THE RIBBED PINE-BORER

THE RIBBED PINE-BORER[1]

Rhagium lineatum Oliv.

Walter N. Hess

Order, *Coleoptera* Family, *Cerambycidae*

The ribbed pine-borer (*Rhagium lineatum* Oliv.) is one of the commonest and most widely distributed species of cerambycids in North America. It is especially abundant in the vicinity of central Pennsylvania and about Ithaca, New York, where this study was conducted. Since these insects are very abundant and the limited literature concerning them contains little information regarding their life history, it has seemed advisable to make a more careful study of their habits.

A number of authors have briefly discussed the economic importance of the insect. Their reports, however, are conflicting and indefinite.

HISTORY OF THE SPECIES

The ribbed pine-borer, originally described by Olivier in 1795, has subsequently been briefly referred to by many authors. Kirby (1837) reports the insect from latitude 54°, and also from Massachusetts. Harris (1842) found the larvae of the species living between the bark and the wood of pitch pine. He states that they attack living trees, often extensively loosening the bark, which falls off in large flakes as a result and the trees die. LeConte (1850) states that the insects are found from Maine to Chihuahua, Mexico.

Rathvon (1862) describes the larva as a whitish grub about an inch long. He found larvae in large numbers just underneath the bark of trees, which they caused to fall off in large pieces, frequently resulting in the death of the trees. Packard (1883) reports the larvae as very common under the bark of pines that have been cut down for a year or more. He found the chief injury to consist in the loosening of the bark, which forwards the decay of dead timber. Hopkins (1899) found the insects to be very common bark borers, mining under the bark

[1] The author is indebted to Professor Glenn W Herrick and Dr Robert Matheson, of the Department of Entomology at Cornell University, under whose direction this study was made.

of dying and dead pine trees. He records the presence of larvae on July 14, pupae in October, and adults on April 8, May 5 and 9, October 17, and December 19.

Felt (1906) thinks these insects should not be considered injurious to living trees, as they live in rotten wood. Their operations, together with those of associated insects, soon loosen the bark so that it falls off in large sheets. Felt found the grubs transforming to adults during the latter part of the summer, in specially constructed pupal cells underneath the bark.

SYNONYMY

The ribbed pine-borer belongs to the order Coleoptera, family Cerambycidae, subfamily Cerambycinae, genus Rhagium, species *lineatum*. This species was first described by Olivier (1795) as *Stenocorus lineatus*, but was later placed in the genus Rhagium. Several workers, chiefly European, consider this insect the American form of the European species *inquisitor*, and hence give it varietal rank under this species as *Rhagium inquisitor lineatum* Oliv. There seems to be good reason for considering this species the same as the European *inquisitor*; however, since American workers list the American form as a distinct species, it is so considered in this discussion.

DISTRIBUTION

The ribbed pine-borer is commonly and widely distributed throughout the greater part of North America. It has been reported from twelve States in this country, in addition to Chihuahua (Mexico), Vancouver, and the Mackenzie River region of Canada. The States from which it has been reported are Maine, Massachusetts, New York, Pennsylvania, Virginia, North Carolina, Maryland, Louisiana, Michigan, New Mexico, Idaho, and Oregon. From these data it seems probable that the beetle ranges in distribution from northern Mexico to central Canada, extending across the continent from coast to coast wherever pine is found.

The species *inquisitor*, with which this species is often grouped, is widely distributed in the Old World. It has been reported from Europe, Siberia, Syria, and Japan.

HOSTS

All of the common species of pine in New York and Pennsylvania are attacked by the ribbed pine-borer. The species most commonly found

infested are the white pine (*Pinus strobus* L.), the pitch pine (*Pinus rigida* Mill.), and the red pine (*Pinus resinosa* Ait.).

These insects are usually reported as pine insects, and it seems probable that they attack all or nearly all species of pines throughout the United States and southern Canada. The writer has never found them infesting other conifers, such as larch and spruce, though it is possible that they may attack these at times.

METHODS OF BREEDING

Numerous attempts were made by the writer to determine the molts of this insect, but with little success. For this purpose pieces of bark were taken to the college insectary, cavities were made on the inner side of the bark, and larvae were placed in these cavities and covered with strips of celluloid as shown on Plate VIII, 5 and 6. The bark was kept in dark, moist jars, where it was easily accessible for examination. Though these larvae lived for many months in an apparently normal condition, they never reached maturity. For making shorter observations, such as that of the pupal stage, this process was very satisfactory.

LIFE HISTORY AND DESCRIPTIONS

The adult

This species, *Rhagium lineatum* Oliv., no doubt owes its specific name to the three smooth, rather strongly elevated, lines or ribs extending lengthwise along each elytron. The beetle is elongate, rather robust, and black mottled with reddish brown and gray. The greater part of its surface is covered with grayish hairs, giving it a grayish pubescent appearance.

The head, which is slightly narrowed behind the eyes, is attached to the thorax by a short neck. The antennae are short, scarcely reaching the bases of the elytra; they are not enveloped by the eyes but are inserted in front of and between them. The maxillary palpus is longer than the labial palpus; the last segment of each is bluntly pointed. The labrum is free. The eyes are oblong and slightly emarginate. The mandibles are flat, acute, and fringed on the inner margin.

The thorax is cylindrical, not margined, and much narrower than the elytra. It is armed on each side with an acute tubercle.

PLATE VIII

1. *Rhagium lineatum*, male

2. *Rhagium lineatum*, female

3. Larva of *Rhagium lineatum*

4. Pupa of *Rhagium lineatum*

5. Inner view of pine bark, showing celluloid strip underneath which are various stages of *Rhagium lineatum* larvae

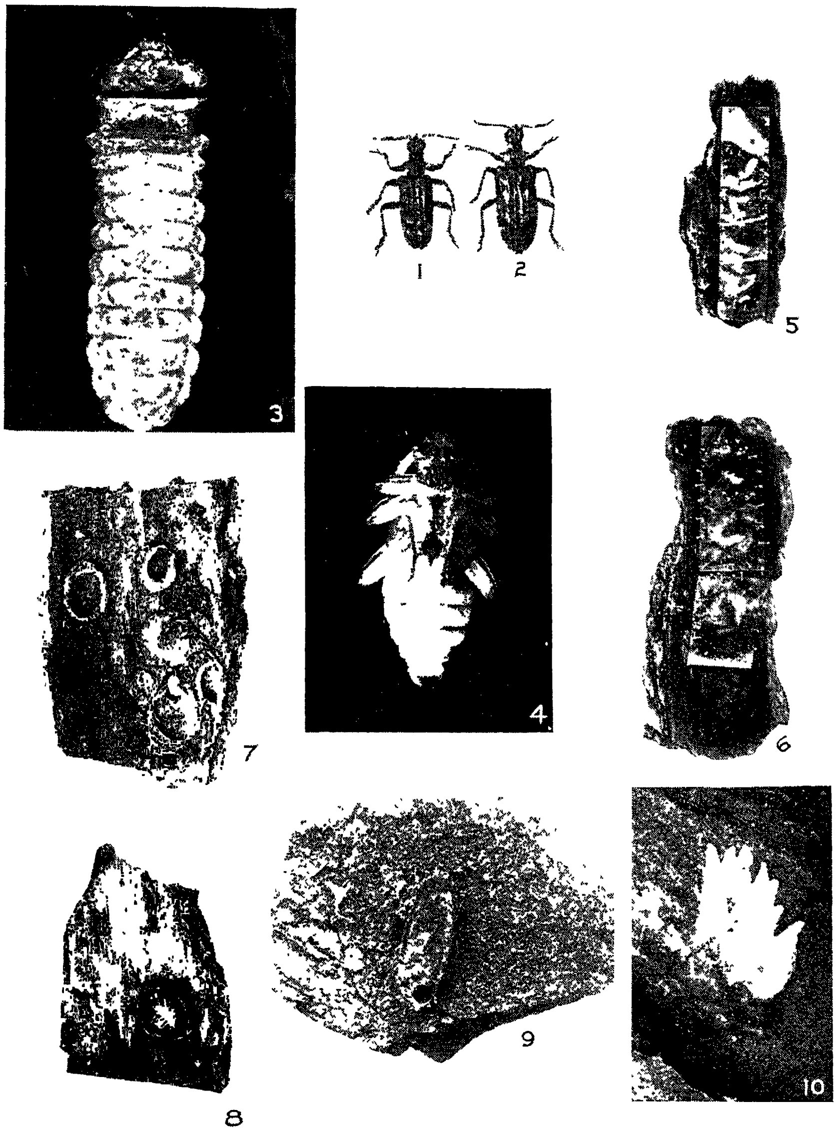
6. Inner view of pine bark, showing the arrangement of celluloid strips used in rearing larvae and pupae

7. Inner view of pine bark, showing four pupal cells. Photograph taken on April 8. The strips of wood woven into the frass in constructing the cells can be distinctly seen. The depressions at the sides of the pupal chambers were made by the adults in preparation for emergence. The lower cell shows a hole made by a woodpecker

8. Inner view of pine bark, showing in the pupal cell a larva of *Rhagium lineatum* which has been killed by a fungus

9. Pupal cell of an *Atanycolus simplex* which has parasitized a *Rhagium lineatum* larva. The exit hole of the parasite can be seen at the lower end of the pupal cell. The head of the parasitized larva is lying at the upper left side of the pupal cell

10. Egg mass on pine bark, exposed by removing a strip of the loose outer bark



The front coxae are conical and prominent; their cavities are open and are angulated externally. The front tibia has no oblique groove on the inner margin. The hind tibial spurs are terminal. The prosternum projects prominently between the coxae.

The elytra are gradually narrowed from about the middle to the apex. The intervals between the longitudinal ridges are coarsely and sparsely punctate.

The chief character that usually distinguishes this beetle is the extensive projection of the prosternum between the prominent fore coxae. Its general pubescence mottled with grayish brown and black, together with the short antennae, usually readily identifies this species.

The sexes are of the same general uniform coloration, but usually differ in two distinguishing characters: (1) the female (Plate VIII, 2) is about 3 millimeters longer and proportionally larger than the male (Plate VIII, 1); and (2) the tip of the abdomen is exposed in the female, while in the male it is entirely concealed by the elytra. The insects vary in length from 12 to 18 millimeters. Those found in small trees with thin bark, and hence scanty food, are usually smaller than those found in larger trees.

During the warm days of early spring the beetles become active in their pupal cells, and gradually begin gnawing through the bark to the exterior. The time of emergence is usually during the last week in April, but this may vary a week or more, depending on weather conditions. The beetles are active as soon as they emerge, and fly readily if disturbed.

Since these insects winter as adults the reproductive organs have had sufficient time to mature. In the spring the female's ovaries are full of large eggs. Copulation occurs as soon as the adults emerge. It occurs frequently, and a pair may remain in copula for several hours. In fact, during the first few days after emergence, this process may be repeated again and again at different times. One pair was taken in copula as late as the last week in June.

Although this beetle is a pine insect, and although it feeds on the bark after becoming an adult, it ceases to feed on pines after emerging. It then becomes a pollen feeder, feeding on such flowers as the dogwood — a habit which it has in common with many of its near relatives among the cerambycids.

The egg

When laid, the egg is pure white in color and is somewhat viscous, with a thin, fragile shell. It is ovoid in shape, being widest near the anterior end and tapering slightly toward the posterior. The shape, however, varies considerably, since owing to the softness of the shell it is easily modified by the shape of the crevice in which the egg is deposited. The entire surface is marked with very irregular elongate areas (fig. 61). The egg measures 1.9 millimeters long by 0.7 millimeter wide.

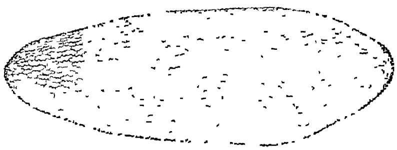


FIG. 61. EGG OF RHAGIUM LINEATUM, SHOWING MARKINGS

The egg stage lasts from eight to ten days, varying with weather conditions. In emerging, the young larva ruptures the egg in the lateral anterior region, usually on the right side. This it does by rubbing the sides of its head against the sides of the chorion, finally slitting the latter longitudinally. On each side of the head is a group of coarse setae which probably function in this process.

The larva

The newly hatched larva (fig. 62) is whitish in color and is slightly flattened. It is more rounded, however, than the mature larva, resembling rather the typical cerambycid type. The head and the thorax are slightly wider than the abdomen. The head is light brown in color, as are also the mouth parts except for the mandibles, which are dark brown toward the tips. At each side of the head is a group of coarse setae with dark brown chitinized basal parts, while scattered over the entire larva are a number of slender, elongate setae.

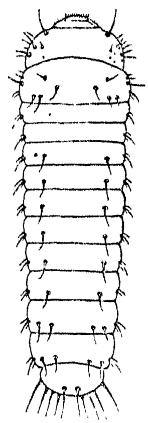


FIG. 62. FIRST INSTAR OF LARVA, DORSAL VIEW

Very soon after emergence, the newly hatched larva works its way through the outer bark into the cambium layer, where the larval life is spent. The larva at this stage is very delicate and soon perishes unless it reaches the cambium layer, where it begins at once to feed.

The mature larva (Plate VIII, 3) is long and is very much flattened, as a result of which it has been incorrectly called a flat-headed borer

(Kellogg, 1905). The head is very large and is slightly wider than the prothoracic segments. It has a triangular incision behind, the apex of which is met by a curved line passing back from the outside of the antennae and dividing the epicranium into two areas. The clypeus is short and wide. The labrum is about twice as wide as it is long, and is moderately rounded in front. The antennae are small and two-segmented, the second joint being blunt at the tip. The mandibles are large, with three cutting teeth. The maxillae are composed of only two segments besides the three-segmented palpus. The labium is large, with a prominent ligula which is slightly rounded at the front edge. The labial palpi are two-segmented.

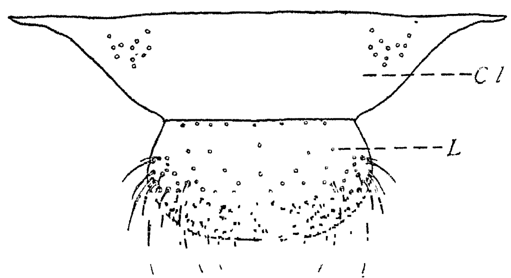


FIG. 63. CLYPEUS AND LABRUM, DORSAL VIEW

The prothorax is of about the same width as the other thoracic segments, but is more than twice as long. It has a flat, chitinized surface. The thoracic legs are slender and are composed of four segments.

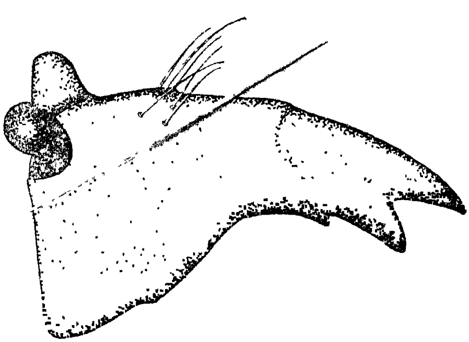


FIG. 64. LEFT MANDIBLE, DORSAL VIEW

The abdominal segments increase slightly in length posteriorly to the eighth, which is longer but narrower than the preceding ones. The ninth segment is of about the same length but is narrower than the eighth. The tenth is scarcely visible from above, being only about one-fourth as wide as the ninth; it is deeply cleft posteriorly.

The mature larva measures from 25 to 30 millimeters in length, with a maximum width of 6 millimeters in the region of the head and the prothorax. The width of the first abdominal segment is 5 millimeters.

This larva may undoubtedly be recognized by its habitat in the cambium of recently killed pine trees, by its relatively large size when mature, and by its broad, flattened head and body.

The mouth parts of the larva

Since these larvae closely resemble in appearance the flat-headed borers, the prothorax and the head are very wide and flat, resulting in a rather broad, short clypeus and labrum (fig. 63). The clypeus (Cl) is very wide at its basal part but tapers anteriorly to join the labrum. The labrum is about twice as wide as it is long, and bears on its dorsal side many long bristles and sense pits.

The mandibles (fig. 64) are broad and heavily chitinized, and bear near the apices three rather sharp cutting teeth which fit them for both cutting and chewing.

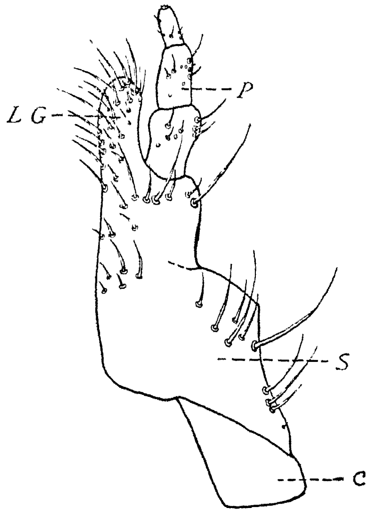


FIG. 65. MAXILLA, VENTRAL VIEW
C, cardo; S, stipes region; LG, undifferentiated lacinia and galea; P, palpus

The maxillae of the larva (fig. 65) are of a much simpler type than those of the adult. The cardo (C) is a distinct sclerite, triangular in shape. The stipes (S) and the lacinia and galea (LG) are not differentiated but are represented by one segment; near the apex on the inner margin are many long bristles, which probably represent the region of the future lacinia. The palpus (P) is three-segmented.

The labium (fig. 66) is large and covers the greater part of the lower side of the head. The submentum (SM) is broad and short. The mentum (M), while narrower than the submentum, is broad and flat. It bears the ligula (L), from which arise the two-segmented labial palpi (P). The greater part of the surface of the labium, but more especially the anterior edge of the ligula, bears numerous long bristles and sense pits.

The pupa

Pupation begins in the latter part of August and continues until late in October. Because of the varying temperature at that time of the year, the pupal period varies considerably. The individuals that pupated in August were found to emerge in from sixteen to twenty days, while those that pupated later took a month or even more to complete their pupal period. Some were found that wintered as pupae, but in every case observed these died before spring. When the adults emerge they are nearly white, and they require from two to five days to become fully colored.

The pupa (Plate VIII, 4) measures from 12 to 18 millimeters in length. It is white in color and rather convex in shape, and is without any special distinguishing markings. Scattered over its surface are many small setae, or spines.

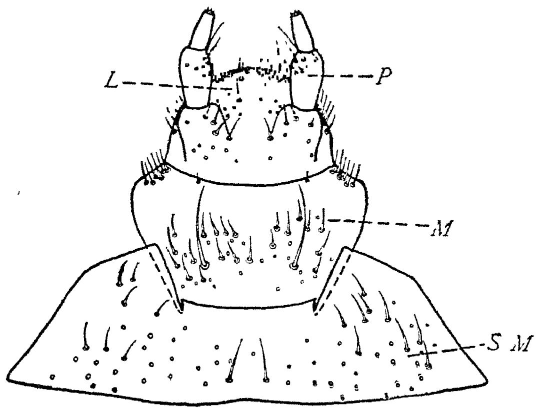


FIG. 66. LABIUM, VENTRAL VIEW
SM, submentum; M, mentum, L, ligula, P, palpus

HABITS

Of all the insects infesting the pine, few are commoner than, or as interesting to observe as, this species of cerambycid. Where the insects were studied in New York and Pennsylvania, they have been found during the winter months in large numbers, both as larvae and as adults, underneath the bark of white, red, and pitch pine. Here the larvae feed on the decaying tissues of the cambium layer.

The adults, which emerge in early spring, can be found during the last of May and in June on pines that have recently died. These insects always prefer the larger trees, and in this region the pitch pine is preferred to the other species, due possibly to the heavier bark which offers the insect more food and better protection. Trees less than six inches in diameter seldom, if ever, are infested with this insect; in fact, efforts have been made, by using cages, to have females oviposit on logs of this

size, with negative results. Where the insects have been found in trees of about this size, they frequently die before maturing, due probably to scanty food and to too little protection from cold and diseases. So far as is known, they never infest either trees that have been dead for more than three years or healthy living trees. They have been found in trees that had been injured by fire or other agencies on one side but were alive and healthy on the other side. The insects no doubt do material damage to such trees in hastening their death, not only by eating into the tissues that may be alive but also in opening and exposing the injured side to water and fungus attacks.

The normal time for these insects to oviposit on pine is in the spring following the death of the trees. The insects will oviposit on the trees again the second year, but only in rare instances will they do so the third year, and never the fourth year in so far as could be determined. In fact, by the third year the cambium layer is so nearly decayed that little is left for the larvae to feed upon.

The insects have been found from the very base of the stumps of the infested tree to near the top, where the trees were about six inches in diameter. They seldom are seen above this, and never in the limbs unless these happen to be very large. An idea of the number of individuals that may be found in an infested tree is given by notes made in regard to a tree cut on March 10, 1916. The tree was 16 inches in diameter at the base and was infested to a height of about 30 feet. It had been dead for two years, and so two broods were present. There were found 195 adults representing the first year's brood, and 155 larvae representing the second year's brood. These insects were rather uniformly distributed throughout the tree. In some cases they were as close together as two or three inches, while in other cases they were as much as a foot apart.

In badly infested trees the mines of these insects are more or less continuous by the end of the second or the third year, often separating the bark from the trees and not infrequently causing it to fall off. It is probable, however, that the burrows of other insects aid in this process.

Differing from most other cerambycid larvae, the larvae of this species move about comparatively little, but feed in all directions from a rather stationary point until all food within reach is consumed. They then move to one side or the other, leaving a large amount of frass behind them. Until the larvae are about three months old they make no special effort

to protect themselves from enemies. Toward fall, however, they construct about themselves a wall from débris, somewhat resembling that of the pupal cell. In the spring the larvae leave their winter cells for food, but during this second summer they usually keep themselves more or less protected by such a barrier. This they tear down and rebuild as they move about for food. As a result of this moving about, a rather extensive area, in the form of a blotch mine, is finally excavated.

During the early part of August of the second year the larvae prepare to pupate. This they do by enlarging and strengthening the chambers in which they have recently been feeding, forming what are called pupal cells (Plate VIII, 7). These cells are oval in shape, are about $\frac{1}{2}$ by $\frac{3}{4}$ inch in size, and lie just underneath the bark. They are constructed of frass which these or other insects have discarded, and are lined with strips of wood which the larvae tear from the bottom of the cells and push firmly into their walls. The excavation of the wood insures the insects plenty of room as well as a better protection against their enemies.

During late summer and early fall the second-year larvae transform to pupae, which in a period of from four to six weeks change to adults. They remain in the pupal cells over winter, emerging as adults the following spring.

SEASONAL HISTORY

Shortly after copulation, the female can be found on the bark of pine trees that have recently died. She walks over the bark, constantly searching with her ovipositor for crevices between the layers of the corky outer bark, in which she deposits her eggs in masses of from one to twenty-five or more, depending on the suitableness of the cavity (Plate VIII, 10). The writer found masses of eggs that hatched at different intervals, indicating that the insects may oviposit in the same cavity more than once.

Egg laying continues from about the middle of May until the last of June or the first of July. Since the eggs all mature at about the same time, the number laid by a single female can be easily ascertained. This number was found to vary from 120 to 165, indicating that the number is comparatively constant.

The eggs hatch into young larvae in from eight to ten days. As soon as they are hatched, they work their way through the bark, where they feed during their larval life on the tissues of the cambium layer.

Since this insect requires two years to complete its life cycle, the first winter is spent in the larval stage. From the time of hatching until late summer, the larva feeds freely in the cambium, but toward fall it constructs about itself a defensive wall of frass. In this condition it spends the winter. During the second summer the larvae usually keep themselves protected by such a defense, moving about only as they need a fresh supply of food. Unlike most larvae, they do not feed in definite channels, but move about irregularly, excavating a blotch-like mine which is often rather extensive.

Toward fall (about September) of the second year the larvae transform to pupae. About three weeks later they transform to adults. In this condition the insects pass the second winter. Toward spring the adults gradually gnaw their way through the bark, and emerge about the first of May. Though they feed very little before emerging, they eat a part of the bark as they bore their way to the exterior. They now no longer feed on the pine, but become pollen feeders like many other cerambycids. After emerging they soon copulate, and about the middle of May begin oviposition.

ECONOMIC IMPORTANCE

Rhagium lineatum, in the strict sense, can hardly be considered as an insect of economic importance in so far as any damage to living pines is concerned. Though its attack is limited to the region of the inner bark and the outer sapwood, it no doubt causes considerable damage to recently dead timber. Its excavations are usually extensive, and as a result the bark is frequently loosened, allowing moisture to enter. When water has once gained access, it is held by the large masses of frass. This is favorable for fungous growth, and hence the decay of the tree is hastened.

During the second and third years after the trees die, the exit holes made by the emerging adults admit large quantities of water, other insects, and fungi, by means of which the log is soon rendered useless for commercial purposes.

Natural control

In the control of the ribbed pine-borer, as in that of many other injurious species, nature has provided enemies which, under favorable conditions, are very effective in reducing their numbers. A wet season not only

makes it difficult for this insect to work, but develops fungi which attack all stages of the insect, especially the larvae (Plate VIII, 8). This is especially true in the case of trees with thin bark, for such trees are less resistant to moisture and the insects may become wet. Under such conditions the larvae, the pupae, and even the adults often die from fungus attacks. Those that survive until winter are often killed by frosts, which under such conditions are destructive to them.

The newly hatched larvae, while searching for an easy access to the inner bark, often expose themselves to predatory enemies which help in reducing their numbers. Birds, chiefly the woodpeckers, are probably the most important of these predatory enemies (Plate VIII, 7). It is not uncommon to find infested trees where these birds have removed from one-half to two-thirds of the larvae and adults during a single winter. Ants are usually common on the trees where the adult beetles are ovipositing. Though the insect tries to place her eggs in a secluded crevice, the newly emerged larvae often expose themselves. Ants have been observed carrying off both eggs and young larvae, chiefly the latter, as food.

Numerous centipedes, and larvae of staphylinids and carabids, are frequently found under the bark with the larvae of this insect, and may feed on them.

Though the insect constructs about itself a defensive wall, it seems probable that this wall is often ineffective against these enemies, especially in trees on which the bark has become loosened. Large carpenter ants have been found in the pupal cells of the ribbed pine-borer, but whether or not they are definitely harmful is not known.

A larval parasite, *Atanycolus simplex* Cresson,[2] which was reared from certain larvae, seemed fairly effective in reducing the numbers of this insect, especially farther south in Pennsylvania. In no case, however, were more than about five per cent of the larvae found infested. In New York this parasite is exceptionally rare, infesting only about one per cent of the larvae. When this parasite is mature it emerges from the larva and constructs a pupal cell underneath the bark (Plate VIII, 9). This occurs during the early fall. The adult emerges the following June. The remnants of the old Rhagium larva can often be seen attached to the pupal case of this parasite.

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[2] Identified by S. A. Rohwer, of the Bureau of Entomology, Washington, D. C.

Artificial control

The insect can be artifically controlled by cutting all recently killed pines and removing the bark before the first of March. This will kill the larvae and the adults, and will do much to lessen attacks the following season. Where possible, the placing of newly felled logs in water will prevent attack. Putting logs in wet places will greatly reduce infestation, though it may hasten the decay of the timber. Repellents such as carbolineum, applied in May, will usually prevent oviposition.

A few years ago the ribbed pine-borer was exceptionally abundant about Ithaca; but during the past few years, due to the improved methods employed in this region by the Department of Forestry, at Cornell University, these insects, together with many of the more injurious forest insects, have nearly disappeared. This has been largely due to the practice of cutting and removing all trees as soon as they die or are found to be dying.

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AGRICULTURAL EXPERIMENT STATION

THE LECITHIN CONTENT OF BUTTER AND ITS POSSIBLE RELATIONSHIP TO THE FISHY FLAVOR

GEORGE CORNELL SUPPLEE

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CONTENTS

THE LECITHIN CONTENT OF BUTTER AND ITS POSSIBLE RELATIONSHIP TO THE FISHY FLAVOR

THE LECITHIN CONTENT OF BUTTER AND ITS POSSIBLE RELATIONSHIP TO THE FISHY FLAVOR[1]

George Cornell Supplee

The commercial value of butter is based to a great extent on its quality, which in turn is determined by its flavor. The commercial grading of butter on this basis, and the recognition of certain characteristic defects, have resulted in the establishment of certain terms more or less descriptive of the flavors found. Among the terms commonly applied to the flavors in butter are such words as *metallic, fishy, oily, rancid, tallowy.* Since the presence of any of these flavors carries with it a reduction in commercial value of the butter, considerable effort has been made to determine their causes and prevent their development. Unfortunately most of these efforts have not met with a high degree of success. This may be ascribed to several reasons, among which are the following: lack of positive identification of the same flavor by different investigators; lack of adequate chemical methods for the isolation and measurement of the small amount of substance capable of producing the flavor; and lack of cooperation between the chemist, the bacteriologist, and the experienced butter judge.

Fishiness in butter, with which this investigation is primarily concerned, is usually described as a flavor resembling that of salmon or mackerel, altho the names of other varieties of fish are occasionally used to describe the flavor more explicitly. While the typical fishy flavor in butter is readily recognized by experts, it is often accompanied by a more or less oily condition which tends to create differences of opinion as to its exact nature. But if the opinion of butter judges of long experience is to be considered as trustworthy, it may be said that the true fishy flavor is entirely distinct from the oily flavor even tho the oily condition may precede or accompany it.

PREVIOUS INVESTIGATIONS

The earlier investigations bearing on fishiness in dairy products have been largely confined to milk and butter. One instance is recorded, however, in which this condition was observed and studied in evaporated milk.

[1] Also presented to the Faculty of the Graduate School of Cornell University, December, 1918, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

Harding, Rogers, and Smith (1900)[2] report the fishy flavor in a sample f milk brought to the New York State Agricultural Experiment Station t Geneva in 1900. The source was traced to a single animal in the herd, ut investigation failed to locate any pathological condition or any regularity in the feeding which might cause the trouble. Attempts to eproduce the flavor by inoculating milk with bacteria isolated from this ow's udder also failed. The same authors mention also an instance rought to their attention by W. E. Griffith, in which a peculiar flavor eveloped in June butter after storage at 18° to 22° F. This flavor was escribed by butter experts as fishy.

Piffard (1901) discusses the fishy flavor in dairy products, and suggests ne possible relationship between certain algae found in stagnant water, nd fishiness in milk and butter. His theory is supported by the fact nat the flavor is often produced in water by the growth of algae and iatoms, and he believes, therefore, that cows having access to such ater may transmit the condition to milk. Referring to the flavor in utter, he considers the idea that salt may be responsible and mentions ne ability of salt to absorb flavors and odors of materials stored near it.

Harrison (1902), discussing butter defects at about the same time, tates that the characteristic off-flavors of butter — fishy butter being pecifically mentioned — are caused by the growth of undesirable bacteria 1 the cream.

O'Callaghan (1902) published certain observations on fishiness in ustralian butter. He states that he has found this condition in butter nly two hours old. From his investigations he concludes that *Oïdium ictis* is the causal agent. Later (O'Callaghan, 1908) he elaborated on is former views, concluding that *Oïdium lactis* associated with the lactic-cid bacteria in cream will usually produce a fishy flavor in the butter. Ie mentions the presence of the defect in unsalted butter, and recommends the improvement of sanitary conditions in the creameries, and asteurization, as a remedy. His conclusions have not been confirmed y other investigators.

Rogers (1909), after a rather exhaustive study of the occurrence and ause of fishy butter, confirms many observations commonly noted in onnection with this trouble but is unable to confirm the observations ' O'Callaghan. He also seemingly eliminates the theory that trimethyl-

[2] Dates in parenthesis refer to *Bibliography*, page 150.

amine is directly responsible for the flavor. After studying the effect of high-acid cream, overworking, and the consequent increased oxygen content of the butter, and by conducting bacteriological investigations, he concludes that high-acid cream is essential to bring about the condition, altho he points out that not all butter made from such cream develops the fishy flavor. In this respect he states (page 20 of reference cited) that "fishy flavor may be produced with reasonable certainty by overworking the butter made from sour cream." From his viewpoint the probability that microorganisms are the cause falls into disfavor by the advancement of the opinion that "fishy flavor is caused by a slow, spontaneous, chemical change to which acid is essential and which is favored by the presence of small amounts of oxygen" (page 20 of reference). More recently the same author (Rogers, 1914, a and b) points out that fishiness in butter may be preceded by an oily or a metallic flavor, and reiterates his views that the evidence is against the theory that the fishy condition is of a bacterial nature. He also states (1914 b) that "fishy flavor is said to occur rarely or not at all in unsalted butter and it is possible that the salt furnishes certain conditions which are essential to the development of the flavor."

Reakes, Cuddie, and Reid (1912) find no significant differences in the bacterial flora of fishy and of high-grade butter, and, in agreement with Rogers, state that "the development of fishy flavour in butter arises as a result of a chemical change inducing a splitting-up of some of the constituents into compounds possessing this peculiar character of smell and taste, the factors responsible for such change being apparently a degree of high acidity of the cream and overworking."

Hunziker (1916) states that high pasteurization temperatures (185° F.) when used on sour cream tend to produce a very poor quality of butter, which often has a disagreeable oily taste suggestive of fishiness. He points out that this is particularly true when cows are on green pasture and the butterfat contains a rather high percentage of olein, which may be oxidized with relative ease in the presence of high temperatures and high acid.

Hammer (1917) reports that he found a can of evaporated milk which possessed a marked fishy flavor and odor and from which he was able to isolate an organism heretofore undescribed. He gives to this organism the name *Bacterium ichthyosmius*, which was suggested by Dr. A. W.

Dox. The description of the organism seems to indicate that it is closely allied to the Proteus group. By inoculation experiments Hammer was able to reproduce the flavor in milk and cream under both aerobic and anaerobic conditions. He noted that the intensity of the odor was increased by the addition of alkali to the milk after the incubation period. He was unable, however, to produce fishiness in butter by direct inoculation or by inoculating the cream before churning. Bacteria counts at various intervals during the storage period showed an immediate decrease in numbers in salted butter, and an increase during the first few days in unsalted butter followed by a pronounced decrease.

Washburn and Dahlberg (1918), while studying the influence of salt on storage butter, found that salted butter was more likely to turn fishy in storage than was unsalted butter, and furthermore that there appeared to be a tendency toward a progressive development of the flavor thru metallic to oily and finally to fishy.

LECITHIN DECOMPOSITION IN BUTTER AS A POSSIBLE CAUSE OF THE FISHY FLAVOR

CHEMICAL CONSTITUTION, PROPERTIES, AND DISTRIBUTION OF LECITHIN

Lecithin, which stands in close relation to the fats, belongs to a more or less definite group of substances known as phosphatides, or phosphorized fats. These bodies appear to be a group of esters containing nitrogen, phosphoric acid, and fatty-acid radicals. Lecithin, which is the best known of the phosphatides, contains two fatty-acid radicals and the nitrogenous base choline, combined with glycerophosphoric acid. According to the kind of fatty acid present in the molecule, it is possible to have various types of lecithin, such as stearyl, palmityl, and oleyl. A number of investigators seem to agree that every true lecithin contains at least one oleic-acid radical. There seems to be uncertainty as to whether choline is the only base present in lecithin. MacLean (1909) was able to get only 42 per cent of the theoretical amount from lecithin isolated from heart muscle, and 65 per cent from lecithin of egg yolk. Other investigators have found the same to hold true of lecithin from different sources.

Lecithin has certain properties in common with the fats, particularly with respect to its solvents. It differs, however, by being less soluble

in ether and more soluble in alcohol. It is precipitated from alcoholic solution by acetone; in water it swells to a colloidal mass which on microscopic examination appears as oily drops and threads. It saponifies with alkalies and baryta water, yielding the corresponding soaps, salts of glycerophosphoric acid, and choline. Hammarsten and Hedin (1915) state that it is slowly decomposed by dilute acids and enzymes (lipase). Barger (1914) states that *Bacterium prodigiosus* produces trimethylamine from choline and lecithin; he also cites references to show that lecithin is decomposed during putrefaction, yielding fatty acids, glycerophosphoric acid, choline, and ultimately trimethylamine. Hasebroek (1888) claims that methylamine, ammonia, methane, and carbon dioxide may be finally produced from choline during putrefaction. On being heated with strong caustic soda or potash, lecithin yields trimethylamine, which has a distinct fishy odor, this being one of the characteristic qualitative tests for it. Leathes (1913), in citing the work of various investigators, seems to think that lecithin is rather unstable. He thinks this property is due to the unsaturated oleic-acid radical contained, and offers this as the reason why the substance gives Pettenkofer's reaction. The work of Long (1908), however, seems to indicate that lecithin is more stable than has been generally believed. Koch (1902–03) has shown that various salts will cause lecithin to precipitate as a gelatinous mass, and that acids, if sufficiently dissociated (0.005 M sulfuric), will accomplish the same thing.

Lecithin seems to be widely found in nature, being present in many plant cells and animal fluids. It is particularly abundant in the brain, the nerve tissue, and the yolk of egg. It is also reported as existing in blood corpuscles, blood plasma, lymph, milk, and bile. Since the methods used for the quantitative estimation of lecithin depend on the determination of phosphorus in alcoholic or alcohol and ether extracts, it is doubtful whether the figures given are absolutely correct due to the fact that other phosphatides are extracted and also because the empirical formula used in the calculation may be inaccurate for the particular lecithin involved. Altho there have been conflicting statements as to whether milk contains lecithin, there seems to be sufficient evidence that it does. The results obtained by Nerking and Haensel (1908) are submitted in table 1:

TABLE 1. THE LECITHIN CONTENT OF VARIOUS MILKS
(From Nerking and Haensel)

Kind of milk	Percentage of lecithin		
	Highest	Lowest	Average
Human, 10 samples	0 080	0 024	0 050
Cow's, 17 samples	0.116	0 036	0 063
Ass's, 6 samples	0 039	0 006	0 016
Ewe's, 4 samples	0 167	0 051	0 083
Goat's, 11 samples	0 075	0 036	0 049
Mare's, 8 samples	0 017	0 007	0 011

Glikin (1909), studying the lecithin and iron content of milk, reports 0.0515 per cent lecithin in whole milk, 0.05 per cent in cream, and 0.1329 per cent in human milk. Fetzer (1911), studying the lecithin content of milk under pathological conditions, finds that it is lower in milk from cows suffering with mastitis than in milk from normal cows. He finds also that the lecithin content decreases as the fat decreases. The work of Bordas and De Raczkowski (1902) indicates that the amount of lecithin varies with the lactation period. They find that it is at the maximum at the beginning, and gradually decreases during the remainder of the period. Their observations were from seven cows.

THEORETICAL DISCUSSION

Trimethylamine as a decomposition product of lecithin was brought to the attention of the writer as a possible cause of the fishy flavor in butter about three years ago, when he was working with lecithin isolated from brain tissue. Altho there seem to be no published data concerning trimethylamine in relation to this subject, and Rogers (1909) claims that it can be worked into butter in large amounts without producing the fishy flavor, it is nevertheless believed by many that this substance is in some way responsible. On boiling lecithin isolated from brain tissue and egg yolk with strong caustic soda, the writer has been able to obtain a distinct oily and fishy odor which was asserted by many to be typical of the odor of fishy butter. The only possible source of such an odor in this case was the trimethylamine derived from the lecithin. This result, together with the fact that there seems to be good evidence that lecithin is present in milk, led to the assumption that the substance

may exist also in butter and that by its decomposition it can slowly liberate trimethylamine with the consequent production of the fishy flavor and odor.

Provided that lecithin can be shown to exist in butter, the above assumption is supported by several facts. It is well known that enzymes are capable of bringing about many chemical decompositions which result from the action of acids and alkalies on organic substances. It also appears to be a fact that butter may contain enzymes derived from the udder, and from the action of bacteria in the milk or the cream before it is made into butter, and furthermore that the activity of such enzymes is not entirely stopped at the temperature at which butter is stored. Hammarsten and Hedin (1915) state that lecithin is decomposed by dilute acids and enzymes. The citations of Hasebroek (1888), Barger (1914), and others show that lecithin is decomposed by bacteria yielding choline, which finally yields trimethylamine. It is also a well-known fact that this substance in very small amounts possesses a distinct fishy odor, but in concentrated solution it has a strong ammoniacal odor. Speaking of the former property, Davis (1912), quoting Taylor, states that the " odour [referring to the peculiar fishy odor suggestive of herring brine] is gradually developed by adding lime to a solution of the base, but requires some time to reach its maximum intensity."

In addition to the foregoing facts the writer has observed certain features that may have some bearing on this problem. In inspecting butter used in the Navy, it has been noticed that certain samples of cream evolved a peculiar fishy odor on the addition of alkali used for titration. This phenomenon was first brought to the attention of the writer by A. M. Besemer, and has since been confirmed by a number of men, some of whom have wide reputation as butter judges. Since trimethylamine is a base which is liberated from its acid combinations by alkalies, it is quite possible that the odor mentioned above was due to this substance's having been liberated from its acid combination in the cream. If such were the case, it is conceivable that butter made from such cream might, during storage, give up its trimethylamine thru the action of enzymes. In this connection it has been noted that certain samples of old butter, which were not scored as fishy, when brought into contact with a warm solution of soap powder would give off a strong herring-like odor. This phenomenon might also be explained as in the case of the cream. In addition to these features it has been noted that certain samples of fishy

butter may lose their characteristic flavor after a period of time. This has also been observed by other investigators. It is possible that this characteristic may be explained by the fact that, since trimethylamine is extremely volatile, it may pass off, or that the instability of the acid combination changes so that the conditions are not right for its manifestation. The writer has noted a very strong fishy odor in partially decomposed egg yolk held at refrigerator temperature, which had entirely disappeared two weeks later.

On the basis of the foregoing facts and observations and the evident lack of contradiction of most of them with what is known about fishy butter, the following experimental work was planned with the object of determining the possible relationship of trimethylamine to this flavor. In calling attention to the lecithin, it may be stated that the writer is cognizant of the fact that trimethylamine may be produced from other substances. This material has been chosen as the object of study primarily because there is exact knowledge concerning its cleavage and some of the agencies bringing this condition about.

INVESTIGATIONAL WORK

QUALITATIVE DETERMINATION OF LECITHIN IN BUTTER

The first experimental work undertaken was to demonstrate the presence of lecithin in butter, since there appeared to be no reports on this point in the literature. One hundred grams of melted butter was thoroly mixed with sufficient anhydrous calcium sulfate (about one kilogram) so that the mixture retained its dry powdered form to such an extent that it could be readily sifted between the thumb and the finger. The mixture was transferred to a specially constructed percolator and extracted for 48 hours with 95-per-cent alcohol at 60° C. The alcoholic extract was evaporated down and the residue was treated with a small amount of ether, which took up the fat, the fatty acids, and part of the lecithin. The part insoluble in ether was again taken up with warm alcohol, and what may be termed the *lecithin fraction* was precipitated by thoroly cooling the alcoholic solution. The substance thus obtained precipitated in the form of small, wart-like masses, which clung tenaciously to the sides of the beaker. On this material, which presumably contained a high proportion of lecithin, various observations were made and qualitative tests applied. The following characteristics were noted:

On drying at ordinary temperature and pressure the material appeared as a semi-amorphous and oily substance of a pale, dirty yellow color. It was entirely soluble in alcohol but was partially thrown out of solution by the addition of an excess of ether. The precipitate formed in this manner was finely granular and was white in color. In water it formed a semi-colloidal solution which on microscopic examination appeared as minute oily drops. When the watery suspension was heated, the particles would cohere to form a sticky mass which changed to a distinct brown color. Both the dry substance and the watery suspension, when heated with strong caustic soda, gave off a marked fishy odor resembling sometimes dried herring and sometimes salmon oil. This observation was in the great majority of cases confirmed by a number of colleagues. The fishy odor obtained from the material in this manner seemed to furnish positive evidence that lecithin was present. To further strengthen this belief, Pettenkofer's test with sugar and sulfuric acid was applied to the dry material with positive results. The above observations were confirmed with lecithin extracted from fresh butter, salted and unsalted, and from other miscellaneous samples of normal butter.

Altho the evidence that lecithin exists in butter in detectable quantities seemed conclusive, it was decided to determine, if possible, the presence of choline, which, as already pointed out, is one of the components of the lecithin molecule. This was accomplished by boiling the residue of the first alcoholic extract with baryta water, which removed all fat, fatty acids, and fatty-acid radicals of the lecithin in the form of barium soaps. After the barium soaps were filtered off, the excess barium was removed with carbon dioxide, the barium carbonate filtered off, and the filtrate containing choline and barium glycerophosphate evaporated to a sirupy consistency. This residue was then treated with absolute alcohol, in which choline is soluble but barium glycerophosphate is insoluble. On evaporation of the absolute alcohol a small amount of sirupy substance remained. To this material qualitative tests for choline were applied. The most characteristic of such tests is the periodide test described by Staněk (1905), which is made by adding a small amount of strong iodine solution (153 grams of iodine and 100 grams of potassium iodide in 200 grams of water) to an aqueous solution of choline. A positive test is indicated by the formation of a brown precipitate of choline periodide, which on microscopic examination in the presence of the reagent appears as dark brown refractive and notched prisms or rhomboidal

leaflets. On evaporation of the reagent the crystals lose their shape and appear to liquefy, forming brown, oily droplets which again assume their crystalline structure on the addition of more reagent. On the application of this test to the choline obtained from butter lecithin, it was found that the results conformed in all respects to the descriptions of this periodide. The accompanying plate of photomicrographs (Plate VI) shows the characteristic crystals and oily droplets of the periodide formed by the choline from butter. In addition to this test it was shown that the small amount of choline obtained would give off a slight but distinct fishy odor on being heated with solid caustic soda.

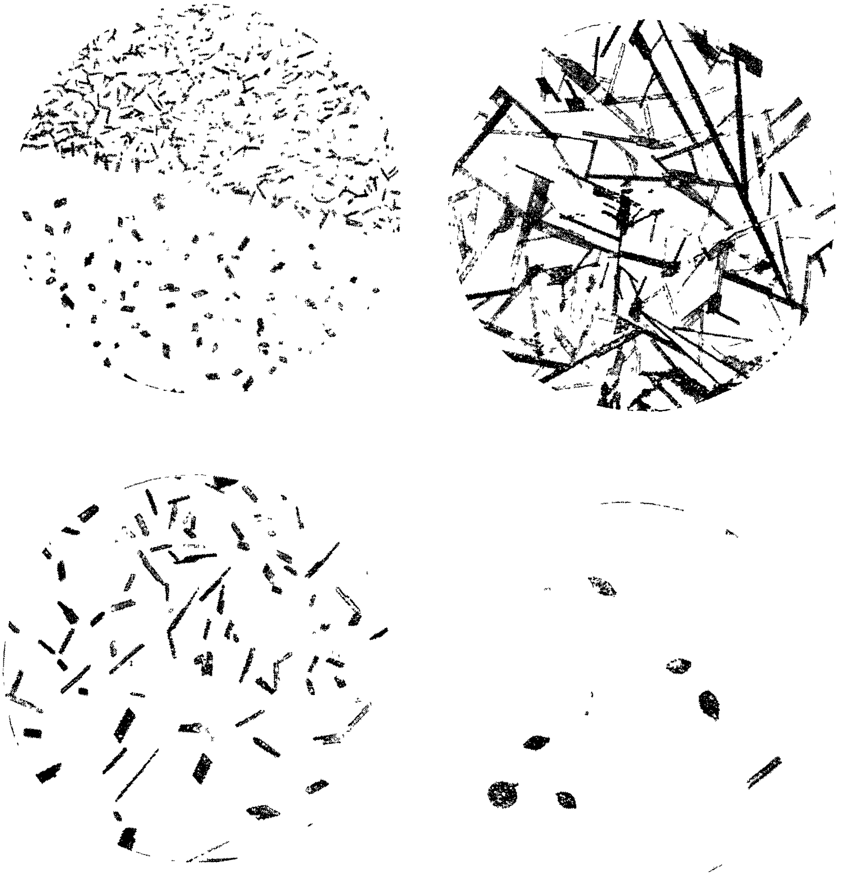
AMOUNT OF LECITHIN IN BUTTER

Since the qualitative tests seemed to leave no room for doubt as to the presence of lecithin in butter, the next step was the quantitative estimation of this substance. In view of the evident difficulty in securing an absolutely pure lecithin free from other phosphatides, the estimations were based on the phosphorus content of extracts and the amount of lecithin calculated according to the formula of the distearyl type. The results of such determinations on various types of butter made from different lots of cream are shown in table 2.

TABLE 2 LECITHIN CONTENT IN VARIOUS BUTTERS*

Sample	Type of cream from which butter was made	Age of butter (days)	P_2O_5 (per cent)	Lecithin, distearyl type (per cent)
1	Raw sweet	6	0 0127	0.0723
2	Pasteurized sweet	6	0 0127	0 07[illegible]3
3	Raw ripened	6	0.0122	0 0693
4	Pasteurized ripened	6	0 0075	0 0433
5	Raw sweet	48	0 0092	0 0522
6	Pasteurized sweet	48	0.0120	0 0682
7	Raw ripened	48	0 0086	0 0188
8	Pasteurized ripened	48	0 0083	0 0471
9	Raw sweet	72	0 0111	0 0631
10	Pasteurized sweet	72	0 0089	0 0505
11	Raw ripened	72	0 0083	0 0471
12	Pasteurized ripened	72	0 0095	0 0540

* These figures were furnished by J. T. Cusick, chemist for the State Department of Agriculture, located at Cornell University.



CHOLINE PERIODIDE CRYSTALS OBTAINED FROM CHOLINE OF BUTTER LECITHIN
Photomicrographs, × 380

A study of table 2 shows a fairly constant lecithin content in butter from various lots of cream and in different types of butter made from the same lot of cream. There is one feature, however, which is worthy of note, and this is that in most instances there is a tendency toward a lower lecithin content in the ripened-cream butter than in that made from unripened cream. This may be significant in the light of the statement by Hammarsten and Hedin (1915), that lecithin is decomposed by dilute acids and enzymes. This fact applied to these results might indicate that the acidity of the cream slowly decomposed the lecithin, and its decomposition products, particularly the glycerophosphoric acid, were washed out with the buttermilk. If such were the case it would be very easy to account for the lower phosphorus content in sour-cream butter.

TRIMETHYLAMINE SALTS OF THE FATTY ACIDS

It was decided that before an attempt was made to correlate trimethylamine with the fishy flavor of butter, this substance should be prepared in a pure state and those characteristics determined which might have a bearing on this particular problem. Trimethylamine was made by heating 50 grams of ammonium chloride and 440 grams of a 40-per-cent solution of formaldehyde in the autoclave at 122° C. for thirty minutes. Any excess formaldehyde was then expelled and the trimethylamine liberated from its hydrochloride by distilling from an alkaline solution. A 10-per-cent solution was easily obtained at the ordinary temperature and pressure. The trimethylamine thus procured was combined with lactic, butyric, oleic, and stearic acids, and also with the mixed soluble and insoluble fatty acids obtained from butter according to the procedure outlined by Browne (1899). While the properties of these acid addition products seemed to offer an interesting field for study, only such of their characteristics are recorded here as might have a direct relationship to the fishy flavor in butter, namely, their stability, volatility, and behavior in the presence of sodium chloride.

The lactic-acid combination with trimethylamine proved to be a relatively stable oily liquid possessing no characteristic taste other than that shown by many common salts. The odor, especially after the liquid had been standing in a stoppered bottle, seemed to be slightly fishy. Evidence on this point is not conclusive because it is possible that this was due to excess trimethylamine added at the time of neutralization and

not shown by the indicator used. Heating seemed to intensify the odor to some extent, which would indicate instability at high temperatures.

The butyric-acid combination with trimethylamine was a substance extremely volatile at ordinary temperatures. The odor greatly resembled fish oil; the taste resembling this product was manifest only when very small amounts were used, and then not regularly.

Oleic acid and trimethylamine formed a soft soap which was very unstable as evidenced by the liberation of the trimethylamine; the greater the dilution, however, the less this condition was manifested. This soap could not be obtained entirely free from water, even at the ordinary temperatures, because of the simultaneous giving-off of trimethylamine and water. This liberation was such that nothing remained but the free acid. Furthermore, on the addition of sodium chloride to its water solution, the sodium ion readily replaced the trimethylamine radical, with the consequent precipitation of the sodium soap and the formation of trimethylamine hydrochloride.

The trimethylamine stearate showed the same characteristics as the oleic soap, but to an even greater extent. Trimethylamine was constantly given off in large quantities, and the only way in which it could be handled as a soap was in a mixture of alcohol and water in a tightly stoppered bottle.

The mixed soluble and insoluble fatty acids combined with trimethylamine showed the same general characteristics as the butyric and stearic combinations, respectively.

The instability of the combinations of fatty acid and trimethylamine can undoubtedly be accounted for by the fact that they are addition products in which the trivalent nitrogen of the latter substance changes to the pentavalent condition in the presence of an acid. The fact that these are weak acids with relatively large molecules is probably also significant. It was observed that the hydrochloride was more stable than the above salts, and that the sulfate was even more stable than the hydrochloride. This instability of the fatty-acid combinations and their reaction in the presence of sodium chloride may have an important bearing on the relation of trimethylamine to fishiness in butter, and may be of particular significance in explaining why the flavor is usually found in salted butter. As yet, however, the relationship is not clear.

EFFECT OF WORKING TRIMETHYLAMINE SALTS OF THE FATTY ACIDS INTO BUTTER

The character of the trimethylamine salts of the fatty acids in pure state seemed to justify the following series of experiments, in which these salts are incorporated into various types of butter for the purpose of determining the possibility of their producing the fishy flavor in the presence of butterfat. In view of the desirability of incorporating the trimethylamine in logical amounts, the following plan was adopted:

The largest quantity of lecithin reported in cow's milk by Nerking and Haensel (1908) was used as the basis of calculation. These authors report 0.116 per cent as the largest amount found in seventeen samples. For the calculations of this experiment, this was assumed to be lecithin of the distearyl type, and it was further assumed to be pure lecithin with the empirical formula assigned to the type named. Granting these assumptions, this amount would yield on complete decomposition the equivalent of 85 parts per million of trimethylamine. This substance alone or in acid combination was therefore added to cream, wash water, or butter on this basis. It is very evident that because of the volatility of some of the materials and because of mechanical loss, none of the samples of butter when completed would contain 85 parts per million of trimethylamine. The method of arriving at the quantity to be added seemed to afford a uniform basis and to approximate in a logical manner the amount of this substance that might be produced in butter. When the fatty acids were used alone they were added in quantities equivalent to the amounts added in the corresponding trimethylamine salts. The addition of the acids was merely for the purpose of checking against the trimethylamine.

In tables 3 to 9 inclusive are shown the comments of various judges on different types of butter containing trimethylamine added as already indicated and incorporated by various means. Because of the great importance of the personal factor in judging butter, an effort was made in all cases to get a number of men familiar with the various flavor defects of the product. In all cases the samples were so labeled that the judges had no knowledge of their contents. They were instructed to comment on the flavor and to work independently of one another, and it is believed that this injunction was carried out. In presenting the results in tabular form the author has intentionally omitted comments having no direct bearing on the fishy flavor.

TABLE 3. EFFECT ON THE FLAVOR OF BUTTER, OF ADDING TRIMETHYLAMINE AND FATTY ACIDS TO RAW SWEET CREAM WITH 0.23 PER CENT ACID AT THE RATE OF 85 PARTS PER MILLION OF THE FORMER

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
AS	Nothing	....	....	....	Oily	Oily	.. .
A	Nothing	. ....	Oily	....	... .	Oily	... .
1 AS	Trimethylamine	Oily	Fishy	. ....	Fishy	....	Fishy
1 A	Trimethylamine	Fishy	.....	......	.....	...	..
2 AS	Trimethylamine lactate	.. ..	......	. ...	. .	.	.
2 A	Trimethylamine lactate	Fishy	Oily	Fishy	Fishy		.
3 AS	Trimethylamine butyrate	Fishy	Fishy	Fishy			...
3 A	Trimethylamine butyrate	Fishy	Oily	. ..	Fishy		. ..
4 AS	Trimethylamine oleate	Fishy	.. ..	. .	Fishy	. ..	. .
4 A	Trimethylamine oleate	..	... .	... .		.	..
5 AS	Trimethylamine stearate	Fishy	. ....	.....	...	. ..	... .
5 A	Trimethylamine stearate	Fishy	. ...	..	.	. ..	.....
6 AS	Trimethylamine and soluble fatty acids	....	.. ..	Fishy	Fishy	. ..	Fishy
6 A	Trimethylamine and soluble fatty acids	Fishy	Fishy	Oily	. ....	..	... .
7 AS	Trimethylamine and insoluble fatty acids	.....	Fishy	Fishy	Fishy	. ...	Fishy
7 A	Trimethylamine and insoluble fatty acids	.....	Oily	. . .	. .	..	Oily
8 AS	Lactic acid	. ..	. ..	. ....	Fishy	. . .	. ...
8 A	Lactic acid	Fishy	Oily	....	.	. . .	... .
9 AS	Butyric acid	Fishy	.. .	. ...		..	. .
9 A	Butyric acid	Fishy	.. .	. . .	Oily	.	..
10 AS	Oleic acid	.	Fishy	Fishy	Fishy	.	... .
10 A	Oleic acid	.. .	. .	...	...	...	... .
11 AS	Soluble fatty acids	... ..	....	....	...	. ... .	.. ..
11 A	Soluble fatty acids	... ..	....	....	....	. ..	......
12 AS	Insoluble fatty acids	. ..	......	....	......	......	....
12 A	Insoluble fatty acids	.	.. ...	.. . ..	... .	....	.....

TABLE 4. EFFECT ON THE FLAVOR OF BUTTER, OF ADDING TRIMETHYLAMINE AND FATTY ACIDS TO RAW SWEET CREAM WITH 0 23 PER CENT ACID AT THE RATE OF 85 PARTS PER MILLION AND THEN WASHING THE BUTTER IN WATER CONTAINING THE SAME CONCENTRATION OF THE VARIOUS SUBSTANCES

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No 6
BS	Nothing	...	...	...	Oily	Oily	...
B	Nothing	...	Oily	...	...	Oily	...
1 BS	Trimethylamine	...	Fishy	...	Fishy	Oily	Fishy
1 B	Trimethylamine	...	...	Fishy	...	Fishy	...
2 BS	Trimethylamine lactate	...	Oily	...	Fishy	Oily	Fishy
2 B	Trimethylamine lactate	Fishy	Oily	Fishy	Fishy	...	...
3 BS	Trimethylamine butyrate	Fishy	Oily	Fishy	...	...	Fishy
3 B	Trimethylamine butyrate	Fishy	...	...	Fishy	...	Fishy
4 BS	Trimethylamine oleate	Fishy	...	...	Fishy	...	...
4 B	Trimethylamine oleate	Fishy	...	...	...	...	Fishy
5 BS	Trimethylamine stearate	Fishy	Oily	Fishy	Fishy	...	Fishy
5 B	Trimethylamine stearate	Fishy	...	...	Fishy	...	Fishy
6 BS	Trimethylamine and soluble fatty acids	Fishy	Fishy	...	Fishy	Oily	Fishy
6 B	Trimethylamine and soluble fatty acids	Fishy	...	...	...	...	Fishy
7 BS	Trimethylamine and insoluble fatty acids	Fishy	Oily	Fishy	Fishy	...	Fishy
7 B	Trimethylamine and insoluble fatty acids	Fishy	...	...	Fishy	...	...
8 BS	Lactic acid	Fishy	...	...	...	...	...
8 B	Lactic acid	Oily	...	...	...	...	...
9 BS	Butyric acid	...	...	...	Oily	...	...
9 B	Butyric acid	...	Fishy	...	Oily	...	...
10 BS	Oleic acid	...	Oily	...	Fishy	...	...
10 B	Oleic acid	...	...	Fishy	...	...	...
11 BS	Soluble fatty acids	...	...	...	...	...	...
11 B	Soluble fatty acids	...	...	...	...	...	...
12 BS	Insoluble fatty acids	...	...	...	...	...	...
12 B	Insoluble fatty acids	...	...	...	...	...	...

TABLE 5. EFFECT ON THE FLAVOR OF BUTTER, OF ADDING TRIMETHYLAMINE AND FATTY ACIDS TO RAW SWEET CREAM WITH 0.23 PER CENT ACID AT THE RATE OF 85 PARTS PER MILLION AND THEN WORKING THE SUBSTANCES DIRECTLY INTO THE BUTTER AT THE SAME RATE

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No 1	No. 2	No. 3	No. 4	No. 5	No. 6
CS	Nothing	...	...	...	Oily	Oily	...
C	Nothing	...	Oily	...	...	Oily	...
1 CS	Trimethylamine	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
1 C	Trimethylamine	...	Fishy	...	Fishy	Fishy	Fishy
2 CS	Trimethylamine lactate	Fishy	Fishy	Fishy	...	Fishy	Fishy
2 C	Trimethylamine lactate	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
3 CS	Trimethylamine butyrate	Fishy	Fishy	Fishy	Fishy	...	Fishy
3 C	Trimethylamine butyrate	Fishy	Fishy	Fishy	...	Fishy	Fishy
4 CS	Trimethylamine oleate	...	...	Fishy	Fishy	...	...
4 C	Trimethylamine oleate	Fishy	Fishy	Fishy	Fishy	...	...
5 CS	Trimethylamine stearate	Fishy	...	...	Fishy	Fishy	Fishy
5 C	Trimethylamine stearate	Fishy	...	...	Fishy	...	Fishy
6 CS	Trimethylamine and soluble fatty acids	Fishy	...	Fishy	...	Fishy	...
6 C	Trimethylamine and soluble fatty acids	Fishy	...	Fishy	...	Fishy	...
7 CS	Trimethylamine and insoluble fatty acids	Fishy	...	Fishy	Fishy	Fishy	Fishy
7 C	Trimethylamine and insoluble fatty acids	Fishy	...	...	Fishy	Fishy	Fishy
8 CS	Lactic acid	Oily	...	Fishy	...	...	...
8 C	Lactic acid	...	...	...	...	...	...
9 CS	Butyric acid	Fishy	Fishy	...	...	...	...
9 C	Butyric acid	Fishy	...	...	Fishy	...	...
10 CS	Oleic acid	...	...	Fishy	Fishy	...	...
10 C	Oleic acid	...	...	Fishy	Fishy	...	...
11 CS	Soluble fatty acids	...	...	...	...	...	...
11 C	Soluble fatty acids	...	...	...	...	...	...
12 CS	Insoluble fatty acids	Oily	.	..	.	Oily	...
12 C	Insoluble fatty acids	Oily	.	..	...	..	...

TABLE 6. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED RIPENED CREAM WITH 0.32 PER CENT ACID, WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 85 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No 2	No. 3	No. 4	No. 5	No. 6
DS	Nothing			.	. .	......	......
D	Nothing....................	.	..	.	.	.....	......
1 DS	Trimethylamine............	.	Fishy	Fishy	Fishy	Fishy	......
1 D	Trimethylamine.............		. .	Fishy	Fishy	Fishy	......
2 DS	Trimethylamine lactate	..	. . .	...	. . .	......	......
2 D	Trimethylamine lactate	...	. . . .	...	.....	....	......
3 DS	Trimethylamine butyrate .	Oily	Fishy	....	Oily	Fishy	Fishy
3 D	Trimethylamine butyrate .	...	Fishy	..	Oily	Fishy	... ..
4 DS	Trimethylamine oleate . . .	..	.	. .	. .	.....	..... .
4 D	Trimethylamine oleate	..	. .	...		....	......
5 DS	Trimethylamine stearate . .			. .	Fishy	Fishy	......
5 D	Trimethylamine stearate . .	Oily	....	....	Oily	Fishy	......
6 DS	Trimethylamine and soluble fatty acids	.	..	Fishy		..	......
6 D	Trimethylamine and soluble fatty acids	...	.....	... .	.	...	......
7 DS	Trimethylamine and insoluble fatty acids	.....	Fishy	....	.	. .	......
7 D	Trimethylamine and insoluble fatty acids	....	Fishy	.... .	. .	.	......
8 DS	Lactic acid.....	Oily	......	. .		. .	......
8 D	Lactic acid..................	.. ...	......	......	.	.	.....
9 DS	Butyric acid..................	Fishy	Fishy	...	.	. . .	......
9 D	Butyric acid........	....	Fishy	...		. .	......
10 DS	Oleic acid..................	......	.....	Fishy	.	.	......
10 D	Oleic acid	..... .		Fishy	..	...	. ....
11 DS	Soluble fatty acids	...	.....	... .	.	. .	. . ..
11 D	Soluble fatty acids	.. ...	..	....	.	..	.....
12 DS	Insoluble fatty acids	Oily	.			Oily	. ....
12 D	Insoluble fatty acids . .	Oily	..	.	.	Oily	......

ABLE 7. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED SWEET CREAM WITH 0.16 PER CENT ACID, WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 85 PARTS PER MILLION

(*S* indicates salted butter)

mple	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
ES	Nothing	.....	......	.....	.....	......	. ..
E	Nothing	.....	....	....	.. ..	....	.
ES	Trimethylamine	Fishy	Fishy	Fishy	Fishy	....	Fishy
E	Trimethylamine	Fishy	Fishy	.....	. ..	....	Fishy
ES	Trimethylamine lactate	Fishy	Fishy	Fishy	Fishy	......	Fishy
E	Trimethylamine lactate	.	Fishy	.....	. ...	.....	Fishy
ES	Trimethylamine butyrate	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
E	Trimethylamine butyrate	. ..	Fishy	......	.....	......	Fishy
ES	Trimethylamine oleate	Fishy	Fishy	......	......	.....	.. ..
E	Trimethylamine oleate	....	Fishy	. ..	. .	......	Fishy
ES	Trimethylamine stearate	...	Fishy	.. .	Fishy	.....	Fishy
E	Trimethylamine stearate	....	Oily	Fishy	Fishy	Fishy	Fishy
ES	Trimethylamine and soluble fatty acids	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
E	Trimethylamine and soluble fatty acids	.	Fishy	Fishy	Fishy	.... .	......
ES	Trimethylamine and insoluble fatty acids	Fishy	Fishy	......	......	Fishy	.
E	Trimethylamine and insoluble fatty acids	.. ..	Fishy	......	....	Fishy	.....
ES	Lactic acid	....	Fishy	......	......	.....	......
E	Lactic acid	. ...	Fishy	.. ...	.....	.... .	......
ES	Butyric acid	Fishy	....	Fishy	....	..	Fishy
E	Butyric acid	Fishy	.....	Fishy	Fishy	Fishy	.. .
ES	Oleic acid	......	......	. ...	Fishy	....	. .
E	Oleic acid	.....	....	.....	Fishy	......	.....
ES	Soluble fatty acids	....	....	.....	Fishy	......	. .
E	Soluble fatty acids	......	.....	....	. ...	Fishy	... .
ES	Insoluble fatty acids	Oily	......	....	. . .	... .	Oily
E	Insoluble fatty acids	Oily	.	. .	..	...	. .

TABLE 8. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED RIPENED CREAM WITH 0.38 PER CENT ACID, WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 40 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges			
		No. 1	No. 2	No. 3	No. 4
FS	Nothing	......	......	......	......
F	Nothing	......	......	......	......
1 FS	Trimethylamine	Oily	Oily	Fishy	......
1 F	Trimethylamine	Oily	Fishy	Oily	......
2 FS	Trimethylamine lactate	Fishy	......	Fishy	......
2 F	Trimethylamine lactate	......	Fishy	......	......
3 FS	Trimethylamine butyrate	Fishy	Fishy	Fishy	Fishy
3 F	Trimethylamine butyrate	......	Fishy	Fishy	Fishy
4 FS	Trimethylamine oleate	......	......	......	......
4 F	Trimethylamine oleate	Oily	......	......	......
5 FS	Trimethylamine stearate	......	......	......	......
5 F	Trimethylamine stearate	......	......	......	......
6 FS	Trimethylamine and soluble fatty acids	......	......	Fishy	......
6 F	Trimethylamine and soluble fatty acids	Oily	......	......	Fishy
7 FS	Trimethylamine and insoluble fatty acids	......	......	......	......
7 F	Trimethylamine and insoluble fatty acids	......	......	......	Fishy
8 FS	Lactic acid	......	......	......	......
8 F	Lactic acid	......	......	......	......
9 FS	Butyric acid	......	......	......	......
9 F	Butyric acid	......	......	......	......
10 FS	Oleic acid	......	......	......	......
10 F	Oleic acid	......	......	......	......

TABLE 9. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED RIPENED CREAM WITH 0.28 PER CENT ACID, OF WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 40 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges			
		No. 1	No. 2	No. 3	No. 4
GS	Nothing	...	...	...	...
G	Nothing	...	...	...	...
1 GS	Trimethylamine	Fishy	Fishy	Fishy	...
1 G	Trimethylamine	...	...	...	...
2 GS	Trimethylamine lactate	Fishy	Fishy	Fishy	...
2 G	Trimethylamine lactate	...	...	...	...
3 GS	Trimethylamine butyrate	Fishy	Fishy	Fishy	...
3 G	Trimethylamine butyrate	...	Fishy	Fishy	Fishy
4 GS	Trimethylamine oleate	Fishy	...	Oily	...
4 G	Trimethylamine oleate	...	...	...	...
5 GS	Trimethylamine stearate	...	...	...	...
5 G	Trimethylamine stearate	...	...	...	...
6 GS	Trimethylamine and soluble fatty acids	...	...	Fishy	.
6 G	Trimethylamine and soluble fatty acids	...	...	Fishy	Fishy
7 GS	Trimethylamine and insoluble fatty acids	...	...	...	...
7 G	Trimethylamine and insoluble fatty acids	...	...	...	...
8 GS	Lactic acid	...	...	...	...
8 G	Lactic acid	...	...	...	...
9 GS	Butyric acid	Oily	...	...	...
9 G	Butyric acid	...	...	...	...
10 GS	Oleic acid	...	...	...	...
10 G	Oleic acid		.	...	...

All of the samples of butter represented in tables 3 to 9 inclusive were scored from three to five days after making. They were then placed in storage for different lengths of time and rescored by two or more judges. The results of this examination are shown in table 10. In this table are listed only those samples showing a fishy flavor by unanimous opinion of the persons judging them.

TABLE 10. PRESENCE OF FISHY FLAVOR AFTER STORAGE, IN BUTTER TO WHICH TRIMETHYLAMINE HAD BEEN ADDED AT THE TIME OF MAKING

Sample	Material added	Age (days)	Comments by judges	
			At time of making	After storage
3 CS	Trimethylamine butyrate	40	Fishy	Fishy
3 DS	Trimethylamine butyrate	267	Fishy, oily	Fishy
3 ES	Trimethylamine butyrate	266	Fishy	Fishy
6 ES	Trimethylamine and soluble fatty acids.	266	Fishy	Fishy
1 FS	Trimethylamine	243	Fishy, oily	Fishy, tallowy
3 FS	Trimethylamine butyrate	243	Fishy	Fishy
3 GS	Trimethylamine butyrate.	243	Fishy	Fishy

The results obtained from these experiments bring out some very interesting facts. While there are several conflicting opinions as to the presence of the fishy flavor in any particular sample, it is nevertheless evident that the greatest number of positive comments is found in the samples containing trimethylamine in one form or another. It will also be noticed that usually the greatest uniformity of such comments is found in the samples containing trimethylamine in unstable form. This is particularly true as to the samples to which trimethylamine was added alone, in combination with butyric acid, or in combination with the mixed soluble fatty acids of butter. These results are in harmony with the volatility, the taste, and the odor of the compounds in pure state. The lack, in a few instances, of a majority opinion with regard to the samples containing trimethylamine oleate, trimethylamine stearate, and trimethylamine with the mixed insoluble acids, might be explained on the basis that, since these substances were so extremely unstable, the trimethylamine had nearly all volatilized before the time of scoring. The greater number of positive comments from the salted butter is also worthy of note, and, from what is generally known regarding the occurrence of the fishy flavor in such butter, it might tend to strengthen the trimethylamine theory of this flavor. Another feature found in this series of experiments is that a greater number of fishy-flavored samples were found where the acidity of the cream was the lowest. This condition is in harmony with the chemistry involved, for the reason that butter made from low-acid cream contains less lactic acid when fresh than is

found in butter made from high-acid cream. It is therefore conceivable that trimethylamine given off by the unstable compounds which were added could not be taken up by the excess lactic acid in the butter to form the more stable trimethylamine lactate. The finding of numerous fishy-flavored samples where trimethylamine lactate had been added to low-acid butter might be explained on the basis that certain conditions were present, possibly particular enzymes, which were capable of bringing about the more rapid dissociation of the trimethylamine lactate, and that due to the absence of sufficient free lactic acid to hold the trimethylamine it passed into the free state. This explanation is borne out by the fact that in the butter from high-acid cream there were a smaller number of samples showing fishiness where the lactate was added. It might be stated further that one would naturally expect to find a greater variety of enzymes capable of bringing about the above-described decomposition in unripened than in ripened cream.

The evidence obtained from the various samples of butter to which trimethylamine butyrate was added, indicates a striking relationship between this substance and the fishy flavor. This seems to be true regardless of the type of butter, and to a certain extent regardless of the presence of sodium chloride. The extremely volatile nature of this substance and its characteristic odor in pure state easily account for the results obtained. The fact that there were more positive comments on the butters containing butyric acid alone than there were on butters containing the other acids alone, indicates that this substance may be a contributing factor in the development of the fishy flavor under natural conditions. This feature indicates also that the fishy flavor may be due to a definite balance between a decomposition yielding trimethylamine and one yielding butyric acid, with the consequent formation of trimethylamine butyrate. This associative action would be entirely possible in storage butter, judging from what is known regarding these fermentations.

In the foregoing discussion the writer has called attention to certain theoretical possibilities which might correlate the findings with what is generally known regarding the various types of normal and of fishy-flavored butter. It may be said, however, that the evidence points strongly toward trimethylamine as a contributing factor in fishy-flavored butter. The amount of this substance responsible for the flavor described as fishy in these experiments is very small. It would be a hazardous

guess to assign a definite quantity, other than to say that in all cases there was less than 85 parts per million.

QUANTITATIVE ESTIMATION OF TRIMETHYLAMINE IN FISHY BUTTER

The results obtained by working trimethylamine into normal butter warranted an attempt to isolate this substance from samples of fishy-flavored butter found on the market. One of the first difficulties met with in this connection was the lack of a method which would accurately measure the small amounts of trimethylamine that would be found. The method that was finally worked out consisted of a combination and modification of the methods of Folin and Macallum (1912) for ammonia and of Budai [Bauer] (1913) for trimethylamine. The adaptation of these methods for this purpose was as follows:

The material in which trimethylamine and ammonia were to be determined was concentrated to a volume not exceeding 15 cubic centimeters. This material was then placed in the proper tube of the Folin apparatus, 10 grams of anhydrous potassium carbonate was added, and the mixture was covered with a thin layer of kerosene to prevent foaming. This mixture was aspirated for five hours. The ammonia and trimethylamine set free by the potassium carbonate was collected in N/10 hydrochloric acid. The excess acid was titrated with exactly N/100 alkali, methyl red being used as the indicator. The results of this titration gave the total amount of the mixture of ammonia and trimethylamine. To this titrated mixture 10 cubic centimeters of a neutral 40-per-cent formaldehyde solution was added. The ammonium chloride present reacted with the formaldehyde to form hydrochloric acid and hexa-methylene-tetramine according to the equation

$$6\ HCOH \text{ and } 4\ NH_4CL = (CH_2)_6N_4,\ 4\ HCL, \text{ and } 6\ H_2O.$$

The hexa-methylene-tetramine being neutral, the hydrochloric acid liberated from the ammonium chloride was titrated and the ammonia was calculated from this titration. Since the trimethylamine hydrochloride present was not affected by the formaldehyde, the trimethylamine was calculated by differences. Since this is essentially a micro method, the technique involved is of the utmost importance. In all cases the volume of the solution to be titrated was kept as nearly constant as possible, and the same amount of indicator was used for each titration. A check on the standard acid and alkali was made with each

determination, and the end-points of all neutralization processes were compared colorimetrically with the standard neutral color. In table 11 are shown the results obtained by this method from mixtures of known amounts of trimethylamine hydrochloride and ammonium chloride:

TABLE 11. EFFICIENCY OF THE MODIFIED MICRO METHOD FOR ESTIMATING TRIMETHYLAMINE AND AMMONIA

Sample	Actual amount of $(CH_3)_3N$ and NH_3 as hydrochlorides (milligrams)		Amount recovered (milligrams)		Percentage	
	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3
1	6.66	6.66	6.64	6.63	99.70	99.55
2	6.66	6.66	6.51	6.63	97.75	99.55
3	2.30	2.30	2.25	2.278	97.83	99.04
4	1.84	1.84	1.79	1.820	97.28	98.91
5	0.92	0.92	0.885	0.935	96.19	101.63
6	0.92	0.92	0.914	0.935	99.35	101.63
7	0.46	0.46	0.442	0.476	96.09	103.48
8	0.46	0.46	0.476	0.476	103.48	103.48
9	0.276	0.276	0.295	0.323	106.88	117.03
10	0.276	0.276	0.295	0.297	106.88	107.61
11	0.276	0.276	0.295	0.297	106.88	107.61
12	.....	0.276	...	0.289	.....	104.71
13		1.81		1.820	......	98.91
14		0.92		0.918	......	99.78
15		0.46		0.459	......	99.78
16		0.614		0.646	......	100.31
17		0.092		0.105	......	114.13

The results shown in table 11 having justified the reliability of the micro method for measuring small amounts of trimethylamine, a number of fishy-flavored samples of butter were subjected to analysis. The butter was thoroly washed in a separatory funnel five times with equal volumes of water acidified with hydrochloric acid at the rate of 25 cubic centimeters of normal acid to the liter. The wash water was then evaporated to a small volume as quickly as possible, and the trimethylamine and ammonia were determined as outlined above.

In table 12 are shown the trimethylamine and ammonia results obtained from fishy butter appearing in commerce and procured from widely different localities. The ammonia results are shown as a matter of

interest but they probably have no direct bearing on this particular problem. Since the experiments with artificially produced fishy flavor seemed to indicate the importance of acidity, the acid values of the samples are also included. The acidity is expressed as cubic centimeters of N/10 sodium hydroxide used to neutralize 20 grams of butter in boiling alcohol. Trimethylamine and ammonia are expressed in parts per million.

TABLE 12. TRIMETHYLAMINE AND AMMONIA CONTENT AND ACID CONTENT OF MISCELLANEOUS SAMPLES OF FISHY-FLAVORED BUTTER

Sample	Trimethylamine (parts per million)	Ammonia (parts per million)	Acid value
1	30.4	11.2	3.8
2	35.4	14.4	5.7
3	28.8	15.2	5.5
4	27.3	26.1	5.4
5	14.0	18.3	6.8
6	None	11.9	3.5
7	None	20.0	2.7
8	26.0	55.0	3.8
9	No analysis	No analysis	3.8
10	No analysis	No analysis	3.0
11	No analysis	No analysis	11.0

The data submitted in table 12 are of considerable interest in view of the history of some of the samples. On arriving at the laboratory, all of the samples, with the exception of samples 5 and 11, were scored as fishy by several judges. These two exceptions were samples of butter sent from a distance and were presumably scored as fishy when shipped but could not be so judged when received. It will be noted that in both cases there was a higher acid value than in any of the other samples, and also that the trimethylamine content of sample 5 is low. With these exceptions the acid value appears to be relatively constant, as does the trimethylamine content with the exception of samples 6 and 7, in which no trimethylamine whatever was found. The majority of these results would seem to point to a definite trimethylamine-acid relationship, as referred to elsewhere in this paper. It is to be regretted that in three instances the sample of butter submitted was too small to warrant analysis. The available data, however, point to trimethylamine as one of the causal agents in fishy-flavored butter.

DEVELOPMENT OF FISHY FLAVOR IN EXPERIMENTAL BUTTERS

In order that the development of the fishy flavor might be more carefully studied, three series of experimental butters were made with the object of determining the influence of pasteurization, of acidity developed during ripening of the cream, of adding lactic acid to the cream, of inoculating butter with lactic-acid bacteria, and of salt. The procedure followed in each of these series consisted of making nine different types of butter, salted and unsalted, from the same original lot of cream. The different series were made at intervals of from three to six weeks. The description of each of the different types of butter in each of the series, and the designation of the samples, are shown in table 13:

TABLE 13. DESCRIPTION OF TYPES OF BUTTER MADE TO STUDY THE DEVELOPMENT OF FISHY FLAVOR

Treatment of cream or butter	Name of sample					
	Salted			Unsalted		
	A series	B series	C series	A series	B series	C series
Raw sweet cream	ASRS	BSRS	CSRS	ASR	BSR	CSR
Pasteurized sweet cream	ASHS	BSHS	CSHS	ASH	BSH	CSH
Raw cream ripened with starter	ARRS	BRRS	CRRS	ARR	BRR	CRR
Pasteurized cream ripened with starter	APRS	BPRS	CPRS	APR	BPR	CPR
Raw cream ripened naturally	ARRNS	BRRNS	CRRNS	ARRN	BRRN	CRRN
Raw sweet cream with *Bacterium lactis acidi* worked into butter	ASRBS	BSRBS	CSRBS	ASRB	BSRB	CSRB
Pasteurized cream with *Bacterium lactis acidi* worked into butter	ASHBS	BSHBS	CSHBS	ASHB	BSHB	CSHB
Raw sweet cream acidified with lactic acid	ASRLS	BSRLS	CSRLS	ASRL	BSRL	CSRL
Pasteurized cream acidified with lactic acid	ASHLS	BSHLS	CSHLS	ASHL	BSHL	CSHL

The samples indicated in table 13 were placed in storage at a temperature of 0° F. or lower, and were scored by three or four judges at various intervals. The results of these scorings are given in table 14. Noncharacteristic flavors are purposely omitted from this table.

TABLE 14. COMMENTS OF JUDGES ON THE DIFFERENT TYPES OF EXPERIMENTAL BUTTERS AFTER VARIOUS LENGTHS OF TIME IN STORAGE AT 0° F.

Sample	Acid in cream (per cent)	Days in storage	Comments by judges			
			No. 1	No. 2	No. 3	No. 4
ASR	0.27	45	Fishy	...	...	...
ASRS	0.27	45	Fishy	...	...	...
ASRS	0.27	130	Fishy	...	...	...
ASRS	0.27	285	...	Fishy	Fishy	...
BSR	0.18	45	Oily	...	Oily	...
BSRS	0.18	45	Fishy	...	Oily	...
BSRS	0.18	285	...	...	...	Fishy
CSRS	0.162	45	...	Fishy	...	...
CSRS	0.162	285	...	...	Fishy	Fishy
BSHS	0.16	45	Metallic	...	Metallic	...
CSH	0.144	130	...	Oily	...	...
CSHS	0.144	45	Metallic	...	...	...
ARR	0.68	45	Metallic	Metallic	...	...
ARRS	0.68	45	Metallic	...	Metallic	...
ARRS	0.68	90	...	Metallic	Oily, fishy	...
ARRS	0.68	130	Metallic	Oily	Metallic	...
ARRS	0.68	285	Metallic	Metallic	Fishy	...
BRRS	0.567	45	...	Metallic	...	...
CRRS	0.567	90	...	Metallic	Metallic	...
CRRS	0.567	285	Fishy	Oily	Metallic	Fishy
BPR	0.52	45	...	...	Oily	...
BPR	0.52	130	Metallic	...	...	...
APRS	0.66	130	...	Fishy	Metallic	...
APRS	0.66	285	...	...	...	Fishy
BPRS	0.52	45	...	Metallic	...	...
BPRS	0.52	130	Metallic	...	...	...
BPRS	0.52	285	...	Metallic	...	...
CPRS	0.562	90	Oily	...	Oily	...
ARRNS	0.675	130	...	Oily	Fishy	...
BRRN	0.576	45	...	...	Oily	...
BRRNS	0.576	45	Oily, fishy	...	...	...
BRRNS	0.576	90	Fishy	Fishy	Oily, fishy	...
BRRNS	0.576	285	Fishy	Fishy	Fishy	Oily
CRRNS	0.600	90	Fishy	...	Oily, fishy	...
ASRB	0.27	45	Fishy	...	...	...
ASRBS	0.27	45	Fishy	...	...	...
ASRBS	0.27	130	Fishy	Fishy	...	...
BSRB	0.18	45	...	...	Oily	...
CSRBS	0.162	45	Oily, fishy	Fishy	...	...
CSRBS	0.162	90	...	...	Oily	...
CSRBS	0.162	285	...	Oily	Metallic	...

TABLE 14 (*concluded*)

Sample	Acid in cream (per cent)	Days in storage	Comments by judges			
			No 1	No 2	No. 3	No. 4
ASHBS ..	0 189	130	Fishy	Oily	.	..
ASHBS . .	0 189	285	.	. .	Fishy	Metallic
CSHBS........	0 144	45	Metallic	Metallic	Metallic	.. .
CSHBS	0 144	90	Metallic	.. .	. .	. .
ASRLS ...	0 638	45	Fishy	. . . .	....	. . . .
ASRLS	0 638	90	. . .	.	Fishy	.. .
ASRLS. . .	0 638	130	. . .	Fishy	Fishy	. . .
ASRLS	0 638	285	Fishy	Fishy	Fishy	Fishy
BSRLS	0 665	45	. ....	Fishy	. .	......
BSRLS	0 665	90	.....	Fishy	. . .	... .
BSRLS... ..	0 665	285	. .	Fishy	Fishy	Metallic
CSRLS..	0 472	45	....	Metallic	.. . . .	. . .
CSRLS	0 472	285	. . . .	Metallic	Fishy	Oily
ASHLS	0 690	130	. .. .	Metallic	Metallic	......
ASHLS	0.690	285	. .	Fishy	Fishy	. . ..
BSHLS..	0.594	45	Fishy	Oily	. . .	. ...
BSHLS	0 594	90	. ...	Fishy	. . ...	. . .
CSHL.	0 504	45	Fishy	. .	. .	......
CSHLS	0 504	45	Fishy	. ..	.. . .	. . .
CSHLS . .	0 504	285		.	Fishy	Oily

In considering the results from the different types of experimental butter, it is evident that there is considerable diversity of opinion among the judges as to the presence or the absence of the fishy flavor in certain samples. It is also evident that there is some relationship between the metallic, oily, and fishy flavors, particularly when these flavors are not sufficiently pronounced to be distinctive as was the case in these samples. This would seem to indicate that there are possibly certain fundamental conditions which are common to the development of each of these flavors.

Even tho there is difference of opinion as to the presence of the characteristic flavors, certain conclusions may be drawn from these experiments. Probably one of the most significant is the presence of the fishy or the metallic flavor in the salted butters. Of a total of 105 characteristic comments, 93 are found in the samples containing salt. Another conclusion which may be drawn from the relative agreement of the judges, is that the fishy flavor appears oftener in the butter made from

high-acid cream than in that from low-acid cream, there being little difference whether the acid was developed by the use of starter, by ripening naturally, or by the addition of lactic acid to raw sweet cream.

These findings, compared with the results obtained from pasteurized cream either churned sweet, ripened with starter, or acidified with lactic acid — all of which showed fewer fishy samples than did raw cream — clearly indicate that the fundamental cause of this butter defect is primarily biological, not brought about by a spontaneous chemical change in which such agencies do not play a part. While it is evident that acid plays an important rôle in the development of the fishy flavor, it is equally clear that there are other important contributing factors. Just what these factors are, is unknown. The variable results obtained from the same type of butter in the different series would indicate that the original cream or milk possessed the unknown factors which in the presence of lactic acid determined the development of the flavor. From the fact that pasteurization tends to reduce the occurrence of the fishy flavor, it is quite probable that these agencies are bacterial enzymes which are only partially inactivated by heat; or it may even be possible that certain microorganisms which are incorporated in the butter from the cream, either in a living or in a dead condition, could on autolysis liberate the enzymes capable of supplying the determining factor. It may also be added that pasteurization may kill certain enzymes and not others, the particular ones that are important being among those killed.

These contentions are further supported by the fact that in the butters made from raw sweet cream there is a suggestion of fishiness after the first storage period which is not found after the longer periods, the disappearance or lack of further development of the flavor being due to the absence of the proper acid condition. It is clear that large numbers of *Bacterium lactis acidi* added directly to butter without their usual accompanying by-products are not the cause of any characteristic change in flavor.

VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS

The importance of acidity in the manifestation of the fishy flavor by trimethylamine, and the relatively constant acid value of the miscellaneous samples of fishy butter found on the market, emphasized the importance of studying this factor in the experimental butters described

above. The variation in acid value of the different types of butter in each of the three series is shown in tables 15, 16, and 17. Results are expressed as cubic centimeters of N/10 alkali necessary to neutralize 20 grams of butter in boiling neutral alcohol.

TABLE 15. VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS OF *A* SERIES AFTER VARIOUS STORAGE PERIODS

Sample	Acid value after various storage periods			
	43 days	86 days	128 days	310 days
ASR	8.8	10 5	10 8	13.0
ASRS	7 4	8 0	8.2	10.0
ASH	5 8	8 6	10 0	12.1
ASHS	5 7	5 9	5 7	7 2
ARR	8 2	8 5	9 3	10.3
ARRS	8.7	8 4	8 6	10 3
APR	7.7	7 9	8.2	9.8
APRS	8 1	7.8	8 0	9 6
ARRN	8.9	8 6	9 2	10 5
ARRNS	8 8	8 4	8.7	10 5
ASRB	9 7	10 4	11.2	15 0
ASRBS	7 4	7 7	7.8	9.8
ASHB	5 7	8 6	9.5	14 3
ASHBS	5 8	5 9	5.8	9 7
ASRL	8 9	8 8	8 8	10 3
ASRLS	8 9	8 9	9.0	10 0
ASHL	7 0	7.1	7.2	8.0
ASHLS	7 4	6 5	7.1	8.5

The data presented in tables 15, 16, and 17 show many interesting features, some of which are worthy of discussion in connection with this problem. It may be stated in the beginning that the variations in acid value of the different types of butter point to biological agencies as the cause of those variations. The lower acid value obtained in nearly all instances from salted butter indicates a preservative action by the salt, a function which is well known. The greatest increase in acidity is

shown in the butter made from raw sweet cream. It is interesting to note that very few of the samples were scored as fishy. When such a condition was suggested, it is to be noted that it occurred after the first storage period, when the acid value was lowest.

TABLE 16. VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS OF *B* SERIES AFTER VARIOUS STORAGE PERIODS

Sample	Acid value after various storage periods			
	20 days	88 days	126 days	286 days
BSR	13 9	14 6	15 2	17 5
BSRS	9 7	9 5	10 0	10 6
BSH	7 3	9 0	10 6	13.4
BSHS	6 3	6 5	6 8	7 6
BRR	10 1	10 2	10 8	11 9
BRRS	10 1	10 1	10 4	11 3
BPR	10 1	10 1	10 0	11 2
BPRS	9 8	10 1	9 6	11 0
BRRN	11 3	11 7	12 6	14.3
BRRNS	11 2	11 7	11 8	13 8
BSRB	13 6	13 5	14 3	15 4
BSRBS	10 6	10 8	10 8	12 0
BSHB	8 1	8 4	9 0	9 2
BSHBS	6 8	6 6	6 8	8 0
BSRL	11 5	11 5	11.6	12 9
BSRLS	11 5	11.1	11.6	12.6
BSHL	9 4	9 4	9 5	11 0
BSHLS	9 5	9 6	9 6	10 1

With reference to the samples from pasteurized cream as compared with those from raw sweet cream, it will be noticed that pasteurization has tended to cause a lowering of the acid value but has not entirely prevented its gradual increase. This would be in accord with possibilities already stated regarding bacterial enzymes. The data show also a retarding action exerted by the acid originally in the cream. This is evident in the butter made from both raw and pasteurized cream ripened

with starter, from raw cream ripened naturally, and from both raw and pasteurized cream to which lactic acid has been added. In comparing the results from these samples it will be observed that cream ripened naturally shows the greatest increase in acid value, raw cream ripened

TABLE 17. VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS OF *C* SERIES AFTER VARIOUS STORAGE PERIODS

Sample	Acid value after various storage periods			
	6 days	48 days	90 days	272 days
CSR	7 8	10.4	11.0	13 5
CSRS	7 0	7.9	8.0	9.7
CSH	4 4	7.6	11 0	12 0
CSHS	4 4	4 7	4.4	5.2
CRR	7.6	9.3	10 4	12.8
CRRS	7 5	8 2	8 4	10 0
CPR	6 6	7 5	8 9	10 0
CPRS	6 5	7.0	7.0	8 2
CRRN	8 5	9.5	10 0	12 9
CRRNS	8 2	9.0	9.1	11 3
CSRB	7 8	10.2	11 8	13 5
CSRBS	6 9	7.4	7.9	9 0
CSHB	4.4	6.5	7.7	7.1
CSHBS	4 4	4.4	4.4	5 2
CSRL	8 3	8.1	8.0	9 8
CSRLS	8.4	8.5	8.4	9 5
CSHL	5 8	6 0	5.9	6 7
CSHLS	6 0	5 7	5.6	6.3

with starter a little less increase, pasteurized cream ripened with starter a still less increase, and cream to which lactic acid has been added the least increase of any in the group. The low acid value caused by the addition of lactic acid might possibly be explained in one of two ways: either the addition of the acid in pure form has tended to inactivate the enzymes, or the lactic acid retained in the butter has been changed to butyric acid during storage — which is entirely possible by enzymatic

action. If such a change as the latter did take place, a lowering of the acid value would be manifested because of the formation of a weaker acid which probably has resulted from the splitting and condensation of two parts of the stronger lactic acid. The possibility of butyric acid being formed in this way might be supported by the fact that the other samples from high-acid cream showed a lower acid value than those from sweet cream but had a higher value than those to which pure lactic acid was added. Even tho this change did take place, however, it is improbable that it could entirely account for the low value indicated. It is more probable that the lactic acid acts as an inhibiting agent. A study of the tables will show that the increase in acid value of the sour-cream butters seems to be greater when the amount of pure lactic acid is lowest in the cream. In using the phrase "pure lactic acid," reference is made to that which was added and also to that developed by bacteria, it being logical to assume that the greatest amount so developed is found in pasteurized cream ripened with starter and the least amount in the raw cream ripened naturally. The condition mentioned above also supports the theory of devitalized enzymes, altho it is more difficult to explain why approximately the same degree of commercial lactic acid has a more marked effect than the acid produced by bacteria. It would seem that the structure of the particular lactic acids involved produced different results in this respect, or that the other acids produced by the bacteria are less inhibitive than the lactic.

Regardless of what the explanation for the variations may be, the data seem to indicate that there may be a relationship between the acid value and the fishy flavor, not so much by a constant condition as by a proper balance between the progressive development of the acid value and some other contributory cause. The most favorable condition would seem to be a very gradual increase in acid value, and one that would be in proper harmony and relationship to some other important and transient factor. If these views can to any degree serve as a basis of explanation, it is comparatively easy to see how an improper balance of any one of the conditions would determine the presence or the absence of the fishy flavor. It might also be conceivable that the intensity of the true flavor would be in inverse proportion to the degree in which these factors were out of equilibrium. Such a conception could explain the occurrence and the disappearance of the flavor in the same sample of butter at different

times, why the fishy, the metallic, and the oily flavors seem to be closely related, and possibly why trimethylamine can be detected in some fishy butters and not in others.

TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS

The micro method already described was used to ascertain the trimethylamine and ammonia content in the experimental butters after different lengths of time in storage. The results of these determinations are shown in tables 18, 19, and 20. Amounts of the substances are expressed in parts per million.

TABLE 18. TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS IN *A* SERIES AFTER VARIOUS STORAGE PERIODS

Sample	After 128 days		After 347 days	
	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3
ASR	None	36.0	None	17.6
ASRS	None	17.2	None	8.4
ASH	None	23.3	None	16.6
ASHS	None	15.0	None	6.8
ARR	None	29.2	None	30.8
ARRS	3.1	16.8	9.4	18.2
APR	None	31.0	None	21.4
APRS	None	20.7	None	24.0
ARRN	None	25.3	None	25.0
ARRNS	13.5	22.4	None	6.8
ASRB	None	18.4	None	24.4
ASRBS	None	22.1	None	12.8
ASHB	None	23.1	11.8	10.8
ASRL	None	17.3	15.2	9.4
ASRLS	None	14.2	6.0	10.7
ASHL	None	16.3	None	12.2
ASHLS	None	19.3	None	8.8

The results shown in tables 18, 19, and 20, altho erratic, are of importance as indicating the variations in decomposition in the same and in different lots of cream, and further emphasize the complexity of a problem of this nature. The same general results with respect to enzymatic activity in salted and in unsalted butter from raw, pasteurized, and ripened cream are found here as were found in connection with the acid values of the same butters. Altho the trimethylamine results are somewhat discordant, a tendency is shown for the presence of this substance

to harmonize with the samples scored as fishy, metallic, or oily. Of 21 samples in which trimethylamine was found, 15 were assigned one of the characteristic flavors by one or more of the judges at some time during the storage period. In 5 of the remaining instances, it is to be noted that, while trimethylamine was found in the same type of butter of the same series, its presence did not harmonize with the characteristic flavor in the salted or the unsalted sample. On the other hand, there were 10 samples of different types of butter which were indicated as having a characteristic flavor by one or more of the judges at some time during the storage period, in which trimethylamine could not be detected.

TABLE 19. TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS IN *B* SERIES AFTER 323 DAYS IN STORAGE

Sample	$(CH_3)_3N$	NH_3
BSR	None	35.2
BSRS	None	18.0
BSH	.	.....
BSHS	53.0	10.2
BRR	None	32.8
BRRS	8.2	21.6
BPR	10.6	23.8
BPRS	9.4	25.0
BRRN	4.7	27.0
BRRNS	None	32.2
BSRB	35.4	29.4
BSRBS	None	20.0
BSHB	5.9	23.0
BSHBS	None	10.4
BSRL	None	23.0
BSRLS	None	17.0
BSHL	None	7.4
BSHLS	None	11.4

While these results are not absolutely conclusive, there is nevertheless an indication that trimethylamine may be one of the contributing factors in the development of the true fishy flavor. It has been shown that this substance is capable of producing a flavor described by butter judges as fishy, this being particularly true in the presence of butyric acid. Furthermore, it has been shown that trimethylamine may be present in fishy-flavored butter. Therefore it would not appear to be beyond the

realm of possibility that the results shown in this paper point to a definite trimethylamine and acid relationship as being the cause of that flavor in butter which resembles the flavor of herring or mackerel brine, and that non-typical flavors resembling other fish products, or the metallic

TABLE 20. TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS IN C SERIES AFTER VARIOUS STORAGE PERIODS

Sample	After 90 days		After 310 days	
	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3
CSR	None	30 2	8 2	33.2
CSRS	None	20 0	None	28 2
CSH	None	32 4	....	....
CSHS	None	19 7	None	11 2
CRR.	None	36 3	None	20 6
CRRS	None	31 2	None	36 2
CPR	None	34 7	None	29 2
CPRS	None	33 2	11 0	27 4
CRRN	None	37 0	18 8	31 8
CRRNS	None	27 6	8 2	29.8
CSRB.	None	33 3	13 0	33 6
CSRBS	None	23 1	5 8	18 6
CSHB	None	31 6	None	31 6
CSHBS	None	34 0	17 6	15 4
CSRL	None	21 4	None	11 8
CSRLS.	None	14 2	None	10 8
CSHL	None	38 7	5 8	20 6
CSHLS	None	19 1	....	....

and the oily flavor, may be due to an unbalancing of this relationship, the occurrence of these flavors being due to factors in which the presence of trimethylamine in detectable amounts is in no way contributory.

BACTERIOLOGICAL STUDIES

In an effort to correlate the preceding observations with the biological aspects of the problem, certain bacteriological studies were carried out. These included a bacterial analysis of fishy- and non-fishy-flavored butters, and inoculations with pure and mixed cultures into choline, lecithin, butterfat, and cream for the purpose of finding, if possible, an organism or a group of organisms which in some way might contribute to the development of the fishy flavor.

Bacterial analysis

Bacteriological examinations of fishy- and of normal-flavored butter from various sources seemed to show no characteristic differences in flora, neither were the quantitative results consistent. Even tho the samples examined did not appear to possess marked differences in flora, cultures of the predominating type were isolated from the fishy samples for the purpose of determining a condition under which they might contribute to the characteristic flavor. The types of bacteria found included a number of acid-producing varieties, both coccus and rod forms. Among the species commonly found were *Micrococcus lactis acidi*, *Mic. lactis albidus*, *Bacterium lactis brevis*, *Bact. aerogenes*, and *Bact. lactis flocculus.*

The bacteria content of certain samples of fishy- and of non-fishy-flavored butter is given in table 21:

TABLE 21. NUMBER OF BACTERIA FOUND IN VARIOUS SAMPLES OF FISHY- AND NON-FISHY-FLAVORED BUTTER

Sample	Character of flavor	Bacteria per gram
1	Strong	1,200,000
2	Fishy	1,400,000
3	Fishy	8,000,000
4	Fishy	21,600,000
5	Oily	30,000,000
6	Fishy	60,000
7	Fishy	135,000
8	Oily	3,900,000
9	Strong	760,000
10	Fishy	23,500
11	Fishy	8,300,000
12	Strong	1,600,000
13	Fishy	340,000
14	Storage	2,600
15	Fishy	390,000
16	Fishy	465,000

Inoculations for the purpose of developing the fishy flavor

The results of previous investigations show that little success has been attained in the attempt to develop the fishy flavor in butter by inoculating the butter itself or by inoculating the cream just prior to churning. If the enzymatic idea as already stated in this paper is to be

upheld, such negative results can be explained by the fact that organisms inoculated into the cream just prior to churning, or into the butter, do not have the opportunity for growth and consequent production of by-products which they would have if allowed to grow in the milk or the cream before it is made into butter. There seems to be good evidence that there is a rapid dying-off of the bacteria in butter after the first few days of storage. Furthermore, it is well known that low storage temperatures do not entirely prevent enzymatic activity. Rogers (1909) shows that, while low temperatures delay the development of the fishy flavor, they do not entirely prevent it. In accordance with these facts it is conceivable that certain enzymes which would be produced by the growth of organisms in the cream, and carried into the butter, would there continue their activity, with the consequent manifestation of certain changes in flavor. Results obtained in the present investigation indicate also the importance of a definite acid relationship. With these factors in mind, the inoculation experiments undertaken in connection with this problem were carried out in a manner that would allow for the manifestation of the possibilities indicated.

Nine organisms, all of which were isolated from samples of fishy butter and *Bacterium ichthyosmius* — which Hammer (1917) found would produce the fishy flavor in milk — were used in these experiments. The same original lot of cream was divided into six parts, and each of these parts was further divided into ten parts, each of which was inoculated with a specific organism. Different methods of handling the six groups of ten inoculations each were carried out in such a way that the effect of acid in conjunction with the specific organism could be determined. Adequate checks were made from uninoculated cream. Pasteurized sweet cream was used as the basis for all inoculations. When the cream was neutralized the acidity was reduced to 0.18 per cent. All samples were made up both salted and unsalted, and were scored after 231 days in storage at a temperature of 0° F. or lower. The results of the experiment as regards salted butter are given in table 22.

It is characteristic of the results of this experiment that none of the samples of unsalted butter showed any of the characteristic flavors and are therefore not included in table 22. It is believed that the results shown in the table clearly confirm the opinion that biological agencies, particularly bacterial enzymes, are responsible to a great degree for the flavors indicated; also, that the fundamental condition necessary for the

TABLE 22. EFFECT ON THE FLAVOR OF SALTED BUTTER, OF INOCULATING CREAM WITH SPECIFIC ORGANISMS UNDER DIFFERENT CONDITIONS

Sample	Treatment of cream	Acidity of cream*		Comments by judges			
		1 (+)	2 (+)	No. 1	No. 2	No. 3	No. 4
1	Raw sweet. . . .	...	0.18	...	...	...	...
2	Pasteurized sweet	..	0.13	...	...	...	...
3	Pasteurized sweet, ripened		0.38	...	...	...	...
4	Pasteurized sweet, ripened and neutralized . .	0.38	0.20	...	.	...	...
5	Pasteurized sweet, acidified with lactic acid...	.....	0.54	Fishy	Fishy	Oily	Fishy
6	Pasteurized sweet, acidified with lactic acid and neutralized. . . .	0.54	0.18	...	.	...	...
D BI	Pasteurized sweet, inoculated with specific organisms and churned at once		0.13	...	...	...	...
D 100			0.13	...	...	...	Metallic
D 23		.	0.13	...	.	...	...
D 12		.	0.13	Tallowy	.	...	Tallowy
D 18		.	0.13	Metallic	.		Oily
D 19			0.13	...		.	...
D 8			0.13	...	.	.	Oily
D 11		.	0.13	...	..	...	. .
D 21		...	0.13	...	..	..	.
D 10		...	.	...	.	.	.. .
E BI	Pasteurized sweet, inoculated with specific organisms and held 24 hours before churning	...	0.45	...	. .	..	. .
E 100		...	0.41	...	. .	Fishy	Tallowy
E 23		. .	0.41	...	Fishy	Metallic	Oily
E 12		.	0.43	...	...	...	...
E 18		...	0.45	...	. .	...	...
E 19		..	0.43	...	...	...	...
E 8		. .	0.46	...	...	...	...
E 11		. .	0.43	...	Oily	Oily	Fishy
E 21		.....	0.43	...	...	...	...
E 10		. ..	0.39	...	.. .	...	...
K BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, and neutralized before churning	0.45	0.18	Metallic	. ..	Fishy	Fishy
K 100		0.41	0.18	...	.. .	...	...
K 23		0.41	0.18	...	...	...	Oily
K 12		0.43	0.18	...	Butyric	Butyric	...
K 18		0.45	0.18	...	...	...	...
K 19		0.43	0.18	...	...	. .. .	...
K 8		0.46	0.18	...	...	...	...
K 11		0.43	0.18	...	Tallowy	...	...
K 21		0.43	0.18	...	...	...	...
K 10		0.39	0.18	...	...	Fishy	...

*1 (+) = acidity at time of neutralizing
2 (+) = acidity at time of churning.

TABLE 22 (*concluded*)

Sample	Treatment of cream	Acidity of cream*		Comments by judges			
		1 (+)	2 (+)	No. 1	No. 2	No. 3	No. 4
N BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, neutralized, and ripened	0.45	0 32	...	...	...	...
N 100		0 41	0 36	...	...	...	...
N 23		0 41	0 35	...	...	...	...
N 12		0.43	0 37	...	...	...	...
N 18		0 45	0 38	...	...	...	...
N 19		0 43	0.36	...	...	...	...
N 8		0.47	0 33	...	...	...	...
N 11		0.43	0 29	...	...	...	...
N 21		0 43	0 39	...	...	...	...
N 10		0 39	0.39	...	...	...	...
R BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, neutralized, ripened, and again neutralized	0 36	0 18	Fishy	Oily	Fishy	Fishy
R 100		0 26	0 18	...	...	...	...
R 23		0 38	0 18	...	...	...	Oily
R 12		0 31	0 18	Butyric	...	...	...
R 18		0 33	0 18	...	...	...	...
R 19		0.32	0 18	...	...	Rancid	...
R 8		0 29	0 18	...	...	...	Fishy
R 11		0 30	0 18	...	...	...	Fishy
R 21		0 32	0 18		...	...	...
R 10		0.29	0 18	...	...	...	...
X BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, and ripened	...	0 29	Metallic	Metallic	Tallowy	Fishy
X 100		...	0 42	...	...	...	Oily
X 23		...	0 40	Metallic	Metallic	Fishy	Metallic
X 12		...	0 39	Butyric	Butyric	...	Strong
X 18		...	0 37	...	...	...	...
X 19		...	0 36	...	...	...	...
X 8		...	0 34	...	...	...	...
X 11		...	0.36	...	...	...	...
X 21		...	0 36	...	...	...	...
X 10		...	0 36		...	...	...

*1 (+) = acidity at time of neutralizing.
2 (+) = acidity at time of churning.

manifestation of these flavors is greatly enhanced by the growth of the organisms in the cream; and furthermore, that a definite acid condition is essential for the development of these flavors, which are potentially possible from the specific bacteria or enzymes. In this experiment it is appreciated that the results are obtained by an associative action with the organisms in the starter and those surviving pasteurization; this fact, however, does not depreciate the specificity of the particular organisms that were inoculated. In reviewing the data from this experi-

ment, it is interesting to note that the sweet pasteurized cream to which lactic acid had been added and which was uninoculated, developed the fishy flavor. The description of the flavor in the same sample of butter by different judges again calls attention to the fact that there seem to be some conditions common to the fishy, the metallic, and the oily flavor.

The most consistent comments from specific organisms seem to be from cultures BI and 23. The former is *Bact. ichthyosmius*, which was obtained from Hammer; the latter is an organism isolated from raw-ripened-cream butter which developed the fishy flavor after two months and retained it for nearly twenty months.

Butter samples E 23 and X BI were analyzed for trimethylamine and ammonia. None of the former substance was found. Sample X BI showed 35.2 parts per million of ammonia, and sample E 23 showed 17 parts per million.

LONGEVITY OF BACTERIUM ICHTHYOSMIUS IN BUTTER

Preliminary experiments with *Bacterium ichthyosmius* indicated that this organism might produce the fishy flavor in butter. It seemed desirable, therefore, to determine its longevity in butter made from the inoculated cream. Results of the quantitative determinations of the bacteria in salted butter containing this organism are shown in table 23; results are given only for those samples to which a characteristic flavor was assigned.

TABLE 23. BACTERIA CONTENT OF SALTED BUTTER MADE FROM CREAM INOCULATED WITH BACTERIUM ICHTHYOSMIUS AND STORED AT A TEMPERATURE OF 0° F. OR LOWER*

Age of sample (days)	Number of bacteria per gram		
	K BI	R BI	X BI
7	23,400,000	10,400,000	....
21	14,400,000	10,100,000	34,250,000
35	10,450,000	8,300,000	28,000,000
49	8,500,000	6,700,000	17,400,000
63	6,300,000	6,350,000	10,150,000
78	1,800,000	4,000,000	11,500,000
91	1,150,000	1,350,000	11,200,000
105	890,000	....	6,400 000
119	750,000	....	5,400,000
134	.....	740,000	....
148	....	355,000	....
162	.....	37,500	4,600,000

* These results were furnished by J. T. Cusick.

The decrease in bacteria content of the salted butter containing *Bact. ichthyosmius* shows that, altho this organism may contribute to the development of the fishy flavor in butter, it does not do so by active multiplication in that medium.

FURTHER STUDIES WITH BACTERIUM ICHTHYOSMIUS

The results obtained with *Bacterium ichthyosmius* seemed to warrant a further study of its relationship to the fishy flavor in butter. The following experiment was carried out with the purpose of determining the conditions in butter under which the development of the flavor could be accelerated. Pasteurized sweet cream was inoculated with this organism and held for two days at room temperature. The butter made from this cream was divided into twelve parts, and to each of these parts a different substance was added. The cream at the time of churning contained 0.23 per cent acid. The treatment of this butter, and the time of occurrence of the fishy flavor as determined by two or more judges, are shown in table 24:

TABLE 24. FISHY FLAVOR AS DEVELOPED IN BUTTER WHICH WAS MADE FROM CREAM INOCULATED WITH BACTERIUM ICHTHYOSMIUS AND TO WHICH VARIOUS SUBSTANCES WERE ADDED

Sample	Substance added to butter	Days in storage				
		52	94	136	175	328
BI 1	Nothing		Fishy	Fishy	Not scored	
BI 2	Berkfeldt filtrate from milk culture of *Bact. ichthyosmius*					
BI 3	Choline, 0.0118 per cent	Oily				
BI 4	Calcium caseinate					
BI 5	Lactic acid, 0.117 per cent	Fishy	Fishy	Fishy	Not scored	
BI 6	Lecithin from butter					Fishy
BI 7	Lactic acid and choline	Fishy				
BI 8	*Bact. lactis acidi* starter					Slightly fishy
BI 9	Berkfeldt filtrate and caseinate					
BI 10	Berkfeldt filtrate and choline.					
BI 11	Berkfeldt filtrate, lactic acid, and choline.					
BI 12	Berkfeldt filtrate made alkaline		Oily	Fishy	Not scored	

All of the butters indicated in table 24 possessed a very disagreeable flavor and odor when fresh but they seemed to improve in quality during storage. The development of the fishy flavor in certain samples shows some very interesting features. In reviewing the results of this experi-

ment it must be borne in mind that the cream from which they were made contained the products of two days growth of *Bact. ichthyosmius*.

The development of the fishy flavor in the sample to which nothing was added, is therefore significant. The earlier occurrence of the flavor in the sample to which lactic acid was added is significant in that it confirms certain observations already noted. The development of the flavor in the sample containing the alkaline Berkfeldt filtrate seems to be about simultaneous with its development in the sample to which nothing was added. The lack of development of the flavor in the samples to which the filtrate was added alone or in combination with other substances, might appear to be contradictory to the enzymatic idea previously expressed. It is believed, however, that this is more than offset by the other data, which point to the necessity of a definite set of conditions that must be met in order to produce the flavor. Such being the case, the absence of the flavor when the filtrate was added may be explained on the basis that the proper equilibrium had been disturbed. The final occurrence of fishiness in the sample containing lecithin is of importance as indicating that this may be the mother substance of the material causing the flavor. Other scattering results do not merit particular discussion at this time.

The trimethylamine and ammonia content of the samples shown in table 24, and their acid value, are given in table 25:

TABLE 25. TRIMETHYLAMINE AND AMMONIA CONTENT AND ACID VALUE OF BUTTER SAMPLES WHICH WERE MADE FROM CREAM INOCULATED WITH BACTERIUM ICHTHYOSMIUS AND TO WHICH OTHER SUBSTANCES WERE SUBSEQUENTLY ADDED

Sample	Age of sample (days)	$(CH_3)_3N$ (parts per million)	NH_3 (parts per million)	Acid value
BI 1	136	7 2	20 7	8 7
BI 2	328	9 4	30 2	9 5
BI 3	328	5 8	28 4	8 5
BI 4	328	4 6	26 8	7 8
BI 5	94	4 7	12 7	8 2
BI 6	328	9 4	25 4	8.0
BI 7	328	8 2	24 0	8 9
BI 8	328	4 6	22 4	8.5
BI 9	328	5.8	25 8	....
BI 10	328	......	.....	9 2
BI 11	328	...	..	9 4
BI 12	136	11 8	17 8	9 3

The relatively constant trimethylamine results shown in table 25 indicate strongly that this substance has been produced in the cream by *Bact. ichthyosmius.*

TRIMETHYLAMINE AND AMMONIA PRODUCTION BY BACTERIUM ICHTHYOSMIUS IN MILK AND CREAM

In order to determine the trimethylamine production by *Bacterium ichthyosmius* in milk and cream, 50-cubic-centimeter quantities of these substances, sterilized, were inoculated with the organism alone and in combination with a lactic-acid starter. The inoculations were held for forty hours at 30° C., and the trimethylamine and ammonia were then determined in 20-cubic-centimeter quantities. The results of these determinations are shown in table 26:

TABLE 26. AMOUNT OF TRIMETHYLAMINE AND AMMONIA PRODUCED IN SKIMMILK AND IN CREAM BY BACTERIUM ICHTHYOSMIUS

Inoculation	Material inoculated	$(CH_3)_3N$ (parts per million)	NH_3 (parts per million)
Bacterium ichthyosmius and starter	Skimmilk	None	84
Bact. ichthyosmius and starter	Cream	204.0	88
Bact. ichthyosmius	Skimmilk	94.4	125
Bact. ichthyosmius.	Cream.	74 7	78

The results presented in table 26 are of great interest as showing beyond a doubt that the fishy flavor produced in milk and cream by *Bact. ichthyosmius* is due to trimethylamine. This being the case, it is obvious that this substance would be carried into the butter, and there, under proper conditions which have already been pointed out, be responsible for the characteristic flavor in that material. With respect to the production of trimethylamine in cream and in milk by this organism, it is desirable to again call attention to the observations of the author, in which the evolution of a fishy flavor was noted on the addition of alkali to sweet cream.

These results are of further importance in that the cream inoculated with starter and *Bact. ichthyosmius* contained a greater amount of trimethylamine than did the cream inoculated with the organism alone. This indicates that an acid condition is most favorable for this particular

fermentation, which would be in harmony with the idea that lecithin furnishes the source of the trimethylamine produced by the organism. The results are supported also by the fact that lecithin is largely associated with the fat, and that according to Hammarsten and Hedin (1915) lecithin is decomposed by dilute acids. Such being the case, it is readily seen that this fermentation brought about by *Bact. ichthyosmius* would be greatly enhanced by the presence of acid. The presence of trimethylamine in skimmilk inoculated with the organism alone might be explained on the basis that the organism was able to produce this substance from proteins as well as from lecithin. Certain data not included in this paper, however, indicate that there is a certain amount of lecithin present in skimmilk. Just why there is no trimethylamine in skimmilk inoculated with the starter and the organism, is more difficult to explain. It may be that the greater acidity in the skimmilk has inhibited the particular factor responsible for trimethylamine production.

PRODUCTION OF TRIMETHYLAMINE FROM LECITHIN AND CHOLINE BY BACTERIAL ACTION

In order to determine, if possible, whether certain organisms found in milk and in butter were capable of decomposing lecithin or choline into trimethylamine, a series of inoculation experiments were carried out. Lecithin alone in 0.3 per cent concentration, and in the presence of lactic acid and salt, was inoculated with a number of organisms, some of which were obtained from milk, some from fishy butter, and some from decomposed egg yolk which had developed the fishy flavor. The following known species were also used: *Bacterium lactis acidi*, *Bact. aerogenes*, *Bacillus prodigiosus*, *B. proteus*, *Bacterium ichthyosmius*, *Pseudomonas liquefaciens fluorescens*, *Oidium lactis.* All organisms were inoculated singly and in various combinations, and the cultures were held at 20° C. for approximately nine months. At the end of that time the cultures were tested for the presence of trimethylamine by heating with alkali. Negative results were obtained from all of the lecithin inoculations tested. Unfortunately, many of the cultures were contaminated with mold, and, since the results could not be considered trustworthy, they were discarded.

The same series of experiments was repeated by inoculating 0.1-per-cent choline alone and in the presence of lactic acid and salt. These cultures were held under the same conditions as were the lecithin inocula-

tions. Trimethylamine was found where *Bacterium ichthyosmius* was inoculated alone, in combination with *Oidium lactis*, and with *Bacterium lactis acidi.* The presence of salt did not seem to prevent the production of trimethylamine. Two organisms which were isolated from milk gave a pronounced test from the choline inoculation, but gave negative results in the presence of lactic acid and salt; *Bacillus prodigiosus* gave a positive reaction from the choline alone; and *Bacterium aerogenes* gave a non-typical test under the same conditions, as did *Pseudomonas liquefaciens fluorescens.* All other inoculations gave negative results.

It would appear from the results of the inoculation experiments that since trimethylamine is produced from choline by *Bacterium ichthyosmius* and certain organisms found in milk, it is quite possible that the fishy flavor and odor found in milk and in butter may be due to this substance's having been produced from the choline of the lecithin molecule. The fact that the two organisms isolated from milk gave a positive reaction and that they were selected at random, indicates that such a fermentation might be found fairly often. These results would therefore seem to point to bacterial agencies as the cause of the fishy flavor, its manifestation in butter being dependent on conditions previously mentioned.

BACTERIAL INOCULATIONS INTO BUTTERFAT

A further attempt was made to produce the fishy flavor by bacterial inoculations into a medium in which all the constituents were fairly definitely known. Pure sterile butterfat from which the phosphatides had been extracted was used as the basis of such a medium. Four series of inoculations were made, using, with a few exceptions, the species that were inoculated into lecithin and choline. These inoculations were stored at a temperature of 0° F. or lower for two hundred and nineteen days, at the end of which time they were examined for the fishy flavor by four judges. Negative results were obtained from all inoculations, not one of the judges pronouncing any of the 120 samples to be fishy in flavor. Whether any of the samples had possessed the flavor at some time during the storage period is difficult to say. All of the samples had a disagreeable tallowy flavor and odor. The composition of each of the four series, and the variation in acid value caused by the inoculations, are shown in table 27. All samples contained from 10 to 12 per cent of moisture and 2 per cent of salt.

TABLE 27. COMPOSITION OF ARTIFICIAL BUTTER AND VARIATIONS IN ACID VALUE CAUSED BY BACTERIAL INOCULATIONS

Sample	Organism or source	Composition and acid value			
		Butterfat	Butterfat and 0.15 per cent of lecithin	Butterfat and Berkfeldt filtrate from starter	Butterfat, Berkfeldt filtrate from starter, and 0.15 per cent of lecithin
1	*Bacterium lactis acidi*	5.2	6.1	6.5	8.8
2	*Oidium lactis*	7.8	5.2	7.8	7.5
3	*Bacterium aerogenes*	7.1	6.8	5.8	7.8
4	*Bacterium ichthyosmius*	5.2	6.8	6.1	7.1
5	*Pseudomonas liquefaciens fluorescens*	6.8	7.1	7.1	7.1
6	*Bacillus prodigiosus*	8.4	6.5	7.5	7.1
7	*Bacillus proteus*	6.1	5.8	6.5	6.8
8	Fishy butter	7.1	7.1	7.5	7.8
9	Fishy butter	6.1	9.1	6.5	7.5
10	Fishy butter	6.5	6.5	7.8	7.1
11	Fishy butter	5.8	6.1	7.8	8.8
12	Fishy butter	7.1	6.1	8.8	8.1
13	Egg yolk	7.1	6.5	8.4	8.1
14	Egg yolk	7.1	6.5	8.8	9.7
15	Strong butter	9.1	6.8	8.4	7.8
16	Strong butter	8.4	8.1	8.4	8.4
17	Normal butter	7.5	6.5	8.4	8.4
18	Fishy butter	8.8	6.8	8.1	8.8
19	Fishy butter	8.1	7.8	7.8	9.7
20	Fishy butter	8.1	6.1	8.1	10.4
21	Fishy butter	6.5	7.1	8.1	11.0
22	Fishy butter	8.4	8.1	9.4	7.8
23	Fishy butter	10.4	6.5	8.4	7.8
24	Egg yolk	9.7	7.1	8.4	7.1
25	Egg yolk	8.8	7.1	6.5	7.8
26	Milk	6.8	6.1	7.5	7.8
27	Milk	7.5	6.5	7.1	9.1
28	Milk	7.8	6.8	6.1	10.0
29	Milk	6.5	8.1	8.1	5.8
30	Check	5.8	5.9	8.1	7.4

The results shown in table 27 are of interest only to the extent that they show the variation in acid value caused by different species of bacteria. Inasmuch as the samples were placed in storage immediately after being inoculated, it is probable that the changes are the result of bacterial enzymes liberated by autolysis, because it has been repeatedly shown that little or no growth takes place during storage.

SUMMARY

The data presented in this paper show beyond a doubt that there is in normal butter a sufficient amount of lecithin to yield, on decomposition, small quantities of trimethylamine, and it is shown also that small quantities of this substance are essential for the manifestation of a fishy odor. Furthermore, it is shown that when this substance is worked into butter under the proper conditions, it produces a flavor described as fishy. These results are most uniform when trimethylamine butyrate is used. An associative fermentation in butter or in cream, with the ultimate formation of this substance, is quite possible. As to whether or not this or some other volatile and unstable combination of trimethylamine is the cause of the natural fishy flavor, remains to be shown more conclusively. Certain data do indicate that trimethylamine is found in some samples of fishy-flavored butter but not in others. Altho it is possible that its presence is incidental in such samples, that is not believed to be the case. In this connection it is worth while to call attention to the confusion between the fishy, oily, and metallic flavors when they are present to only a slight degree. It seems possible that the initiation of the development of these flavors depends on a common fundamental factor. Whether or not any particular one of them develops to its typical flavor would depend on the presence of certain conditions which were specific for that flavor. With this possibility in view, it would be logical to assume that trimethylamine is responsible for the typical herring, or mackerel, flavor and odor in butter, and that the absence of this substance would result in the manifestation of similar but non-typical flavors.

There seems to be no doubt that the presence of a definite acid condition in the butter is essential for the development of the fishy flavor. This condition is best obtained when butter is made from cream containing lactic acid, regardless of whether this is developed by bacteria or added to the cream in the form of the commercial product. Furthermore, the results indicate that, while a definite acid condition is essential, it must be accompanied by some other equally important factor. The data show that this factor is determined by biological agencies. It appears that both these factors must exist in a definite and delicate relationship, and that if the proper equilibrium is disturbed, the characteristic flavor is not manifest. Numerous results and observations indicate that the unknown transient factor is trimethylamine.

The bacteriological aspects of the problem seem to involve the determination of the relationship already mentioned. It is shown that the acid value of butter is to a certain extent regulated by biological factors, probably enzymes. It is shown also that trimethylamine may be produced in milk and in cream, probably to some extent from lecithin, with the consequent production of the fishy flavor in those products. Furthermore, it is shown that *Bacterium ichthyosmius*, which produced the flavor in those substances, would produce the flavor in butter also under certain conditions. It would therefore seem possible that other species of microorganisms might bring about the same type of change. It seems highly probable that the growth of bacteria in the cream before it is made into butter determines the conditions necessary for the later manifestation of the fishy flavor.

The data dealing with lecithin as the source of trimethylamine in milk products are too meager to warrant definite conclusions at this time. However, the results presented herein, taken together with what is known regarding this substance, indicate that this is one of the most logical sources.

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CORNELL UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

THE RIBBED PINE-BORER

WALTER N. HESS

ITHACA, NEW YORK
PUBLISHED BY THE UNIVERSITY

THE RIBBED PINE-BORER

THE RIBBED PINE-BORER[1]

Rhagium lineatum Oliv.

WALTER N. HESS

Order, *Coleoptera* Family, *Cerambycidae*

The ribbed pine-borer (*Rhagium lineatum* Oliv.) is one of the commonest and most widely distributed species of cerambycids in North America. It is especially abundant in the vicinity of central Pennsylvania and about Ithaca, New York, where this study was conducted. Since these insects are very abundant and the limited literature concerning them contains little information regarding their life history, it has seemed advisable to make a more careful study of their habits.

A number of authors have briefly discussed the economic importance of the insect. Their reports, however, are conflicting and indefinite.

HISTORY OF THE SPECIES

The ribbed pine-borer, originally described by Olivier in 1795, has subsequently been briefly referred to by many authors. Kirby (1837) reports the insect from latitude 54°, and also from Massachusetts. Harris (1842) found the larvae of the species living between the bark and the wood of pitch pine. He states that they attack living trees, often extensively loosening the bark, which falls off in large flakes as a result and the trees die. LeConte (1850) states that the insects are found from Maine to Chihuahua, Mexico.

Rathvon (1862) describes the larva as a whitish grub about an inch long. He found larvae in large numbers just underneath the bark of trees, which they caused to fall off in large pieces, frequently resulting in the death of the trees. Packard (1883) reports the larvae as very common under the bark of pines that have been cut down for a year or more. He found the chief injury to consist in the loosening of the bark, which forwards the decay of dead timber. Hopkins (1899) found the insects to be very common bark borers, mining under the bark

[1] The author is indebted to Professor Glenn W. Herrick and Dr. Robert Matheson, of the Department of Entomology at Cornell University, under whose direction this study was made.

ying and dead pine trees. He records the presence of larvae on 14, pupae in October, and adults on April 8, May 5 and 9, October 17, December 19.

lt (1906) thinks these insects should not be considered injurious to g trees, as they live in rotten wood. Their operations, together with of associated insects, soon loosen the bark so that it falls off in large ts. Felt found the grubs transforming to adults during the latter of the summer, in specially constructed pupal cells underneath the .

SYNONYMY

he ribbed pine-borer belongs to the order Coleoptera, family Cerambyc- subfamily Cerambycinae, genus Rhagium, species *lineatum*. This ies was first described by Olivier (1795) as *Stenocorus lineatus*, but was placed in the genus Rhagium. Several workers, chiefly European, ider this insect the American form of the European species *inquisitor*, hence give it varietal rank under this species as *Rhagium inquisitor tum* Oliv. There seems to be good reason for considering this species same as the European *inquisitor*; however, since American workers the American form as a distinct species, it is so considered in this ssion.

DISTRIBUTION

he ribbed pine-borer is commonly and widely distributed throughout greater part of North America. It has been reported from twelve es in this country, in addition to Chihuahua (Mexico), Vancouver, the Mackenzie River region of Canada. The States from which it been reported are Maine, Massachusetts, New York, Pennsylvania, inia, North Carolina, Maryland, Louisiana, Michigan, New Mexico, o, and Oregon. From these data it seems probable that the beetle es in distribution from northern Mexico to central Canada, extending ss the continent from coast to coast wherever pine is found.

he species *inquisitor*, with which this species is often grouped, is widely ibuted in the Old World. It has been reported from Europe, Siberia, a, and Japan.

HOSTS

l of the common species of pine in New York and Pennsylvania are cked by the ribbed pine-borer. The species most commonly found

infested are the white pine (*Pinus strobus* L.), the pitch pine (*Pinus rigida* Mill.), and the red pine (*Pinus resinosa* Ait.).

These insects are usually reported as pine insects, and it seems probable that they attack all or nearly all species of pines throughout the United States and southern Canada. The writer has never found them infesting other conifers, such as larch and spruce, though it is possible that they may attack these at times.

METHODS OF BREEDING

Numerous attempts were made by the writer to determine the molts of this insect, but with little success. For this purpose pieces of bark were taken to the college insectary, cavities were made on the inner side of the bark, and larvae were placed in these cavities and covered with strips of celluloid as shown on Plate VIII, 5 and 6. The bark was kept in dark, moist jars, where it was easily accessible for examination. Though these larvae lived for many months in an apparently normal condition, they never reached maturity. For making shorter observations, such as that of the pupal stage, this process was very satisfactory.

LIFE HISTORY AND DESCRIPTIONS

The adult

This species, *Rhagium lineatum* Oliv., no doubt owes its specific name to the three smooth, rather strongly elevated, lines or ribs extending lengthwise along each elytron. The beetle is elongate, rather robust, and black mottled with reddish brown and gray. The greater part of its surface is covered with grayish hairs, giving it a grayish pubescent appearance.

The head, which is slightly narrowed behind the eyes, is attached to the thorax by a short neck. The antennae are short, scarcely reaching the bases of the elytra; they are not enveloped by the eyes but are inserted in front of and between them. The maxillary palpus is longer than the labial palpus; the last segment of each is bluntly pointed. The labrum is free. The eyes are oblong and slightly emarginate. The mandibles are flat, acute, and fringed on the inner margin.

The thorax is cylindrical, not margined, and much narrower than the elytra. It is armed on each side with an acute tubercle.

PLATE VIII

1. *Rhagium lineatum*, male

2. *Rhagium lineatum*, female

3. Larva of *Rhagium lineatum*

4. Pupa of *Rhagium lineatum*

5. Inner view of pine bark, showing celluloid strip underneath which are various stages of *Rhagium lineatum* larvae

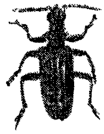
6. Inner view of pine bark, showing the arrangement of celluloid strips used in rearing larvae and pupae

7. Inner view of pine bark, showing four pupal cells. Photograph taken on April 8. The strips of wood woven into the frass in constructing the cells can be distinctly seen. The depressions at the sides of the pupal chambers were made by the adults in preparation for emergence. The lower cell shows a hole made by a woodpecker

8. Inner view of pine bark, showing in the pupal cell a larva of *Rhagium lineatum* which has been killed by a fungus

9. Pupal cell of an *Atanycolus simplex* which has parasitized a *Rhagium lineatum* larva. The exit hole of the parasite can be seen at the lower end of the pupal cell. The head of the parasitized larva is lying at the upper left side of the pupal cell

10. Egg mass on pine bark, exposed by removing a strip of the loose outer bark



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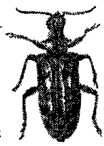

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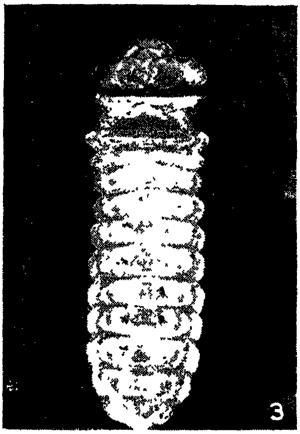

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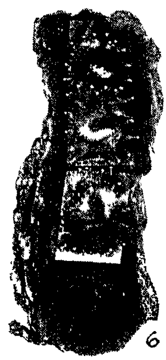

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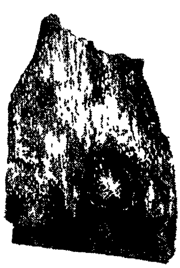

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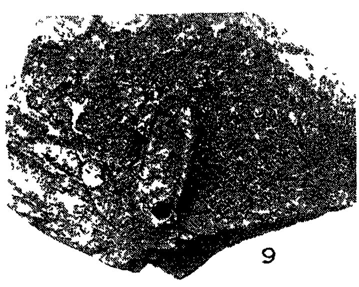

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The front coxae are conical and prominent; their cavities are open and are angulated externally. The front tibia has no oblique groove on the inner margin. The hind tibial spurs are terminal. The prosternum projects prominently between the coxae.

The elytra are gradually narrowed from about the middle to the apex. The intervals between the longitudinal ridges are coarsely and sparsely punctate.

The chief character that usually distinguishes this beetle is the extensive projection of the prosternum between the prominent fore coxae. Its general pubescence mottled with grayish brown and black, together with the short antennae, usually readily identifies this species.

The sexes are of the same general uniform coloration, but usually differ in two distinguishing characters: (1) the female (Plate VIII, 2) is about 3 millimeters longer and proportionally larger than the male (Plate VIII, 1); and (2) the tip of the abdomen is exposed in the female, while in the male it is entirely concealed by the elytra. The insects vary in length from 12 to 18 millimeters. Those found in small trees with thin bark, and hence scanty food, are usually smaller than those found in larger trees.

During the warm days of early spring the beetles become active in their pupal cells, and gradually begin gnawing through the bark to the exterior. The time of emergence is usually during the last week in April, but this may vary a week or more, depending on weather conditions. The beetles are active as soon as they emerge, and fly readily if disturbed.

Since these insects winter as adults the reproductive organs have had sufficient time to mature. In the spring the female's ovaries are full of large eggs. Copulation occurs as soon as the adults emerge. It occurs frequently, and a pair may remain in copula for several hours. In fact, during the first few days after emergence, this process may be repeated again and again at different times. One pair was taken in copula as late as the last week in June.

Although this beetle is a pine insect, and although it feeds on the bark after becoming an adult, it ceases to feed on pines after emerging. It then becomes a pollen feeder, feeding on such flowers as the dogwood — a habit which it has in common with many of its near relatives among the cerambycids.

The egg

When laid, the egg is pure white in color and is somewhat viscous, with a thin, fragile shell. It is ovoid in shape, being widest near the anterior end and tapering slightly toward the posterior. The shape, however, varies considerably, since owing to the softness of the shell it is easily modified by the shape of the crevice in which the egg is deposited. The entire surface is marked with very irregular elongate areas (fig. 61). The egg measures 1.9 millimeters long by 0.7 millimeter wide.

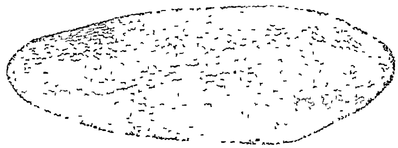

FIG. 61. EGG OF RHAGIUM LINEATUM, SHOWING MARKINGS

The egg stage lasts from eight to ten days, varying with weather conditions. In emerging, the young larva ruptures the egg in the lateral anterior region, usually on the right side. This it does by rubbing the sides of its head against the sides of the chorion, finally slitting the latter longitudinally. On each side of the head is a group of coarse setae which probably function in this process.

The larva

The newly hatched larva (fig. 62) is whitish in color and is slightly flattened. It is more rounded, however, than the mature larva, resembling rather the typical cerambycid type. The head and the thorax are slightly wider than the abdomen. The head is light brown in color, as are also the mouth parts except for the mandibles, which are dark brown toward the tips. At each side of the head is a group of coarse setae with dark brown chitinized basal parts, while scattered over the entire larva are a number of slender, elongate setae.

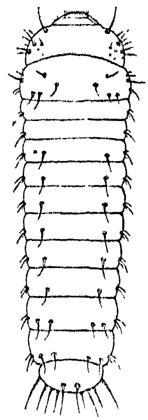

FIG. 62. FIRST INSTAR OF LARVA, DORSAL VIEW

Very soon after emergence, the newly hatched larva works its way through the outer bark into the cambium layer, where the larval life is spent. The larva at this stage is very delicate and soon perishes unless it reaches the cambium layer, where it begins at once to feed.

The mature larva (Plate VIII, 3) is long and is very much flattened, as a result of which it has been incorrectly called a flat-headed borer

(Kellogg, 1905). The head is very large and is slightly wider than the prothoracic segments. It has a triangular incision behind, the apex of which is met by a curved line passing back from the outside of the antennae and dividing the epicranium into two areas. The clypeus is short and wide. The labrum is about twice as wide as it is long, and is moderately rounded in front. The antennae are small and two-segmented, the second joint being blunt at the tip. The mandibles are large, with three cutting teeth. The maxillae are composed of only two segments besides the three-segmented palpus. The labium is large, with a prominent ligula which is slightly rounded at the front edge. The labial palpi are two-segmented.

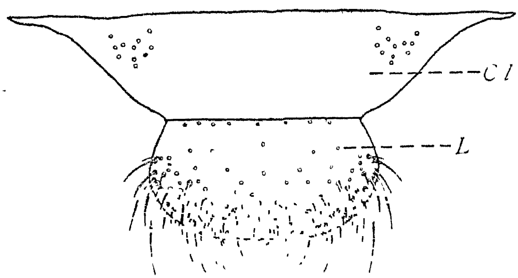

FIG. 63. CLYPEUS AND LABRUM, DORSAL VIEW

The prothorax is of about the same width as the other thoracic segments, but is more than twice as long. It has a flat, chitinized surface. The thoracic legs are slender and are composed of four segments.

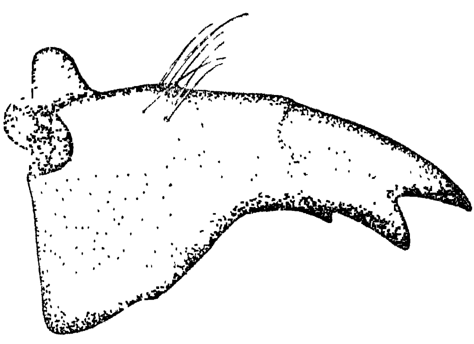
FIG. 64. LEFT MANDIBLE, DORSAL VIEW

The abdominal segments increase slightly in length posteriorly to the eighth, which is longer but narrower than the preceding ones. The ninth segment is of about the same length but is narrower than the eighth. The tenth is scarcely visible from above, being only about one-fourth as wide as the ninth; it is deeply cleft posteriorly.

The mature larva measures from 25 to 30 millimeters in length, with a maximum width of 6 millimeters in the region of the head and the prothorax. The width of the first abdominal segment is 5 millimeters.

This larva may undoubtedly be recognized by its habitat in the cambium of recently killed pine trees, by its relatively large size when mature, and by its broad, flattened head and body.

The mouth parts of the larva

Since these larvae closely resemble in appearance the flat-headed borers, the prothorax and the head are very wide and flat, resulting in a rather broad, short clypeus and labrum (fig. 63). The clypeus (Cl) is very wide at its basal part but tapers anteriorly to join the labrum. The labrum is about twice as wide as it is long, and bears on its dorsal side many long bristles and sense pits.

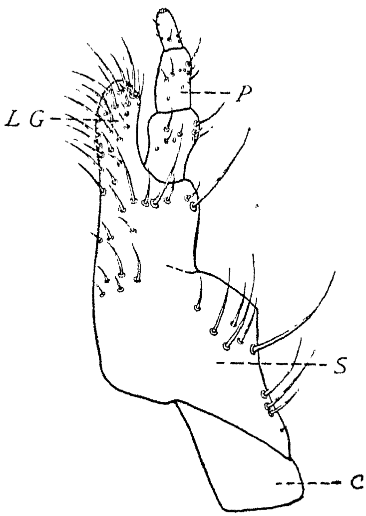

FIG. 65. MAXILLA, VENTRAL VIEW
C, cardo; S, stipes region; LG, undifferentiated lacinia and galea; P, palpus

The mandibles (fig. 64) are broad and heavily chitinized, and bear near the apices three rather sharp cutting teeth which fit them for both cutting and chewing.

The maxillae of the larva (fig. 65) are of a much simpler type than those of the adult. The cardo (C) is a distinct sclerite, triangular in shape. The stipes (S) and the lacinia and galea (LG) are not differentiated but are represented by one segment; near the apex on the inner margin are many long bristles, which probably represent the region of the future lacinia. The palpus (P) is three-segmented.

The labium (fig. 66) is large and covers the greater part of the lower side of the head. The submentum (SM) is broad and short. The mentum (M), while narrower than the submentum, is broad and flat. It bears the ligula (L), from which arise the two-segmented labial palpi (P). The greater part of the surface of the labium, but more especially the anterior edge of the ligula, bears numerous long bristles and sense pits.

The pupa

Pupation begins in the latter part of August and continues until late in October. Because of the varying temperature at that time of the year, the pupal period varies considerably. The individuals that pupated in August were found to emerge in from sixteen to twenty days, while those that pupated later took a month or even more to complete their pupal period. Some were found that wintered as pupae, but in every case observed these died before spring. When the adults emerge they are nearly white, and they require from two to five days to become fully colored.

The pupa (Plate VIII, 4) measures from 12 to 18 millimeters in length. It is white in color and rather convex in shape, and is without any special distinguishing markings. Scattered over its surface are many small setae, or spines.

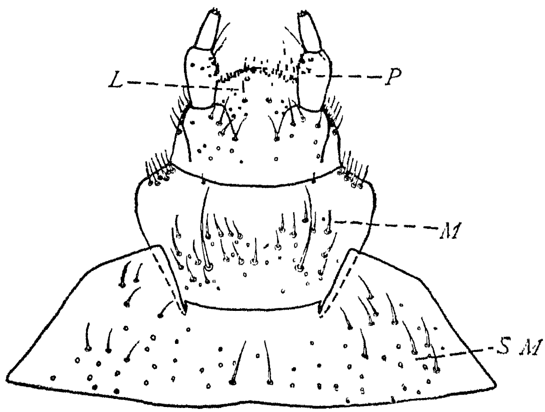

FIG. 66. LABIUM, VENTRAL VIEW
SM, submentum; M, mentum; L, ligula; P, palpus

HABITS

Of all the insects infesting the pine, few are commoner than, or as interesting to observe as, this species of cerambycid. Where the insects were studied in New York and Pennsylvania, they have been found during the winter months in large numbers, both as larvae and as adults, underneath the bark of white, red, and pitch pine. Here the larvae feed on the decaying tissues of the cambium layer.

The adults, which emerge in early spring, can be found during the last of May and in June on pines that have recently died. These insects always prefer the larger trees, and in this region the pitch pine is preferred to the other species, due possibly to the heavier bark which offers the insect more food and better protection. Trees less than six inches in diameter seldom, if ever, are infested with this insect; in fact, efforts have been made, by using cages, to have females oviposit on logs of this

size, with negative results. Where the insects have been found in trees of about this size, they frequently die before maturing, due probably to scanty food and to too little protection from cold and diseases. So far as is known, they never infest either trees that have been dead for more than three years or healthy living trees. They have been found in trees that had been injured by fire or other agencies on one side but were alive and healthy on the other side. The insects no doubt do material damage to such trees in hastening their death, not only by eating into the tissues that may be alive but also in opening and exposing the injured side to water and fungus attacks.

The normal time for these insects to oviposit on pine is in the spring following the death of the trees. The insects will oviposit on the trees again the second year, but only in rare instances will they do so the third year, and never the fourth year in so far as could be determined. In fact, by the third year the cambium layer is so nearly decayed that little is left for the larvae to feed upon.

The insects have been found from the very base of the stumps of the infested tree to near the top, where the trees were about six inches in diameter. They seldom are seen above this, and never in the limbs unless these happen to be very large. An idea of the number of individuals that may be found in an infested tree is given by notes made in regard to a tree cut on March 10, 1916. The tree was 16 inches in diameter at the base and was infested to a height of about 30 feet. It had been dead for two years, and so two broods were present. There were found 195 adults representing the first year's brood, and 155 larvae representing the second year's brood. These insects were rather uniformly distributed throughout the tree. In some cases they were as close together as two or three inches, while in other cases they were as much as a foot apart.

In badly infested trees the mines of these insects are more or less continuous by the end of the second or the third year, often separating the bark from the trees and not infrequently causing it to fall off. It is probable, however, that the burrows of other insects aid in this process.

Differing from most other cerambycid larvae, the larvae of this species move about comparatively little, but feed in all directions from a rather stationary point until all food within reach is consumed. They then move to one side or the other, leaving a large amount of frass behind them. Until the larvae are about three months old they make no special effort

to protect themselves from enemies. Toward fall, however, they construct about themselves a wall from débris, somewhat resembling that of the pupal cell. In the spring the larvae leave their winter cells for food, but during this second summer they usually keep themselves more or less protected by such a barrier. This they tear down and rebuild as they move about for food. As a result of this moving about, a rather extensive area, in the form of a blotch mine, is finally excavated.

During the early part of August of the second year the larvae prepare to pupate. This they do by enlarging and strengthening the chambers in which they have recently been feeding, forming what are called pupal cells (Plate VIII, 7). These cells are oval in shape, are about $\frac{1}{2}$ by $\frac{3}{4}$ inch in size, and lie just underneath the bark. They are constructed of frass which these or other insects have discarded, and are lined with strips of wood which the larvae tear from the bottom of the cells and push firmly into their walls. The excavation of the wood insures the insects plenty of room as well as a better protection against their enemies.

During late summer and early fall the second-year larvae transform to pupae, which in a period of from four to six weeks change to adults. They remain in the pupal cells over winter, emerging as adults the following spring.

SEASONAL HISTORY

Shortly after copulation, the female can be found on the bark of pine trees that have recently died. She walks over the bark, constantly searching with her ovipositor for crevices between the layers of the corky outer bark, in which she deposits her eggs in masses of from one to twenty-five or more, depending on the suitableness of the cavity (Plate VIII, 10). The writer found masses of eggs that hatched at different intervals, indicating that the insects may oviposit in the same cavity more than once.

Egg laying continues from about the middle of May until the last of June or the first of July. Since the eggs all mature at about the same time, the number laid by a single female can be easily ascertained. This number was found to vary from 120 to 165, indicating that the number is comparatively constant.

The eggs hatch into young larvae in from eight to ten days. As soon as they are hatched, they work their way through the bark, where they feed during their larval life on the tissues of the cambium layer.

Since this insect requires two years to complete its life cycle, the first winter is spent in the larval stage. From the time of hatching until late summer, the larva feeds freely in the cambium, but toward fall it constructs about itself a defensive wall of frass. In this condition it spends the winter. During the second summer the larvae usually keep themselves protected by such a defense, moving about only as they need a fresh supply of food. Unlike most larvae, they do not feed in definite channels, but move about irregularly, excavating a blotch-like mine which is often rather extensive.

Toward fall (about September) of the second year the larvae transform to pupae. About three weeks later they transform to adults. In this condition the insects pass the second winter. Toward spring the adults gradually gnaw their way through the bark, and emerge about the first of May. Though they feed very little before emerging, they eat a part of the bark as they bore their way to the exterior. They now no longer feed on the pine, but become pollen feeders like many other cerambycids. After emerging they soon copulate, and about the middle of May begin oviposition.

ECONOMIC IMPORTANCE

Rhagium lineatum, in the strict sense, can hardly be considered as an insect of economic importance in so far as any damage to living pines is concerned. Though its attack is limited to the region of the inner bark and the outer sapwood, it no doubt causes considerable damage to recently dead timber. Its excavations are usually extensive, and as a result the bark is frequently loosened, allowing moisture to enter. When water has once gained access, it is held by the large masses of frass. This is favorable for fungous growth, and hence the decay of the tree is hastened.

During the second and third years after the trees die, the exit holes made by the emerging adults admit large quantities of water, other insects, and fungi, by means of which the log is soon rendered useless for commercial purposes.

Natural control

In the control of the ribbed pine-borer, as in that of many other injurious species, nature has provided enemies which, under favorable conditions, are very effective in reducing their numbers. A wet season not only

makes it difficult for this insect to work, but develops fungi which attack all stages of the insect, especially the larvae (Plate VIII, 8). This is especially true in the case of trees with thin bark, for such trees are less resistant to moisture and the insects may become wet. Under such conditions the larvae, the pupae, and even the adults often die from fungus attacks. Those that survive until winter are often killed by frosts, which under such conditions are destructive to them.

The newly hatched larvae, while searching for an easy access to the inner bark, often expose themselves to predatory enemies which help in reducing their numbers. Birds, chiefly the woodpeckers, are probably the most important of these predatory enemies (Plate VIII, 7). It is not uncommon to find infested trees where these birds have removed from one-half to two-thirds of the larvae and adults during a single winter. Ants are usually common on the trees where the adult beetles are ovipositing. Though the insect tries to place her eggs in a secluded crevice, the newly emerged larvae often expose themselves. Ants have been observed carrying off both eggs and young larvae, chiefly the latter, as food.

Numerous centipedes, and larvae of staphylinids and carabids, are frequently found under the bark with the larvae of this insect, and may feed on them.

Though the insect constructs about itself a defensive wall, it seems probable that this wall is often ineffective against these enemies, especially in trees on which the bark has become loosened. Large carpenter ants have been found in the pupal cells of the ribbed pine-borer, but whether or not they are definitely harmful is not known.

A larval parasite, *Atanycolus simplex* Cresson,[2] which was reared from certain larvae, seemed fairly effective in reducing the numbers of this insect, especially farther south in Pennsylvania. In no case, however, were more than about five per cent of the larvae found infested. In New York this parasite is exceptionally rare, infesting only about one per cent of the larvae. When this parasite is mature it emerges from the larva and constructs a pupal cell underneath the bark (Plate VIII, 9). This occurs during the early fall. The adult emerges the following June. The remnants of the old Rhagium larva can often be seen attached to the pupal case of this parasite.

[2] Identified by S. A. Rohwer, of the Bureau of Entomology, Washington, D. C.

Artificial control

The insect can be artifically controlled by cutting all recently killed pines and removing the bark before the first of March. This will kill the larvae and the adults, and will do much to lessen attacks the following season. Where possible, the placing of newly felled logs in water will prevent attack. Putting logs in wet places will greatly reduce infestation, though it may hasten the decay of the timber. Repellents such as carbolineum, applied in May, will usually prevent oviposition.

A few years ago the ribbed pine-borer was exceptionally abundant about Ithaca; but during the past few years, due to the improved methods employed in this region by the Department of Forestry, at Cornell University, these insects, together with many of the more injurious forest insects, have nearly disappeared. This has been largely due to the practice of cutting and removing all trees as soon as they die or are found to be dying.

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CORNELL UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

A MODIFIED BABCOCK METHOD FOR DETERMINING FAT IN BUTTER

NELSON W. HEPBURN

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CONTENTS

A MODIFIED BABCOCK METHOD FOR DETERMINING FAT IN BUTTER

A MODIFIED BABCOCK METHOD FOR DETERMINING FAT IN BUTTER[1]

NELSON W. HEPBURN

The problem of devising a short method for determining the fat content of butter was formerly a subject of academic rather than practical interest. Within recent years, however, there has been a notable development within commercial systems which has brought with it new demands. The fundamentals necessary to good instruction for the improvement of manufacturing systems have become more fully understood. Increased commercial competition has developed a higher regard for a more accurate accounting of the product as it passes thru the plant, and commercial institutions have insisted on a more far-reaching legal supervision over the composition of their products.

One serious difficulty in meeting these demands with respect to the manufacture of butter has been the lack of a method for quickly and accurately determining the fat content of this product. The purpose of the investigation herein discussed was to develop such a method. Since the Babcock test apparatus is regularly a part of present-day commercial equipment, it seemed that some modification of this method would naturally be the most acceptable. Other modification have been suggested for this purpose at various times (Wiley 1899, Wright 1904, Farrington and Woll 1914, Van Slyke 1916),[2] but no method has appeared which satisfactorily meets the commercial needs.

METHODS OF THE PRESENT INVESTIGATION

One suggested modification of the Babcock test involved the use of an ordinary Babcock cream bottle with a fractional sample of butter. Early in the history of the hand-separator cream industry, samples of cream rich in fat were frequently tested by using a 9-gram sample in an 18-gram bottle. This procedure was often accompanied by a relatively high degree

[1] Also presented to the Faculty of the Graduate School of Cornell University, June, 1918, as a major thesis in [illegible] of the requirements for the degree of doctor of philosophy.

[2] Dates in parenthesis refer to [illegible] 690.

of error, due to the fact that when 9 grams of cream are weighed into an 18-gram bottle any errors in weighing or reading are multiplied by the factor 2. If these errors happen to fall in the same direction, the final results may be far from accurate. · This criticism is even more applicable in the testing of butter than in the testing of cream, since butter is more difficult to manipulate than is cream.

In this investigation, preliminary to the undertaking of the development of a special method a number of samples of butter were tested by the ordinary Babcock method, the cream bottle being used with a fractional sample. This method of manipulation was as follows: Half samples (9 grams) of butter were used in an 18-gram, 40-per-cent cream bottle. A 9-gram sample was introduced into the bottle, 9 cubic centimeters of warm water was added, and this was followed by 17.5 cubic centimeters of sulfuric acid. After thoroly mixing the water, the fat, and the acid, enough more water was introduced to bring the fat up to the base of the neck in the bottle. Tests were then centrifuged at the ordinary rate of speed for a period of five, and then of four, minutes. The samples were then removed from the tester, set in a water bath, and tempered at from 125° to 130° F. Glymol (Hunziker and others, 1910) was added to remove the meniscus in reading. The average readings were multiplied by 2 to give the percentage of fat in the butter. Some of the results of this preliminary study are given in table 1:

TABLE 1. RESULTS OF TESTS MADE WITH AN 18-GRAM, 40-PER-CENT CREAM BOTTLE

Reading			Calculated percentage of fat	Chemical analysis
Minimum	Maximum	Average		
42 25	42 56	42.40	84.74	84 09
42 75	42 75	42.75	85.50	83 99
41 75	42 00	41.87	83 74	82.74
41 25	41 50	41 37	82 74	83 85
42 50	42 50	42.50	85.00	84 21
41 25	41 50	41 37	82 74	83 85
42 00	42 00	42 00	84 00	82 74
41 75	42 00	41.87	83.74	82 76
42.14	42 50	42.32	84.74	83 99
41.50	42.25	41.87	83.74	84.38

The results given in table 1 are typical of. those obtained in testing about one hundred samples of butter, using the fractional sample in the ordinary cream bottle. The relatively high degree of error observed in some of these cases is obviously due to the fact that an exact reading is difficult in this type of bottle and in the final results any errors in manipulation have been doubled. It is evident, then, that uniformly accurate results are not obtained by this method. It therefore seemed advisable to construct a type of bottle in which the final results would be obtained by direct weighing and direct reading.

The problem of developing a test bottle for this purpose was bounded by the following requirements: (1) The bottle must be of such dimensions that it would fit the ordinary Babcock centrifuge; (2) it must be so constructed that the graduated part of the neck would hold all the fat for a given weight of sample; (3) the relation of the diameter of the neck to its length must be such that the graduations would be so spaced as to be easily read; (4) since the error in weighing is inversely proportional to the size of the sample, the weight of the sample must be as great as possible while still conforming to the other requirements.

The Babcock centrifuges now on the market limit test bottles, so far as total length is concerned, to two types, known respectively as 6-inch and 9-inch bottles. In graduating a test bottle of either of these types, it is obvious that if results are to be read directly in terms of percentage of butterfat, the neck of the bottle must, for easy manipulation, hold a quantity of fat from an 18-gram sample somewhat in excess of the maximum percentage of fat that is likely to occur in butter. The average fat content of butter is about 82.5 per cent, while the maximum fat content is not likely to exceed 85 per cent. It can therefore be assumed that a bottle with a maximum reading of 90 per cent would be adequate for butter samples containing high percentages of fat and at the same time would allow for some error in filling and manipulating during the testing process.

In any Babcock bottle of the straight-necked type, one of the most important relations is that of the length of the graduated part of the neck to its diameter. With a given weight of sample, the long, slender neck will allow graduations to be well spaced, which means easy reading, while the short neck of large diameter for the same weight of sample means crowded graduations and difficult reading.

Types of bottles used

Four types of bottles, two 9-inch and two 6-inch, were developed which would meet the foregoing requirements. They are designated in the text as the 9-inch, 18-gram, 90-per-cent butter bottle; the 9-inch, 9-gram, 90-per-cent butter bottle; the 6-inch, 6-gram, 90-per-cent butter bottle; and the 6-inch, 5-gram, 90-per-cent butter bottle.

In a 9-inch, 18-gram, 90-per-cent bottle, the graduated part of the neck must have a capacity of exactly 90 per cent of the sample tested. With an 18-gram sample this would be 16.2 grams. The average specific gravity of butterfat under test conditions, however, is 0.9; therefore, 16.2 grams of butterfat will occupy a space of $16.2 \div 0.9 = 18$ cubic centimeters. The volume of the neck between the graduations 0 and 90 for this type of bottle must therefore be 18 cubic centimeters. In order to get this volume, in a practical bottle the length of the graduated part of the neck must be on the average 141 millimeters and the diameter must be 12.75 millimeters. It was soon discovered that this wide diameter contributed to rather large errors in reading, and the 18-gram bottle was therefore discarded.

Following the method of calculation used for the 18-gram bottle, the graduated part of the neck of a 9-inch, 9-gram, 90-per-cent bottle must have a volume of 9 cubic centimeters. This volume was secured in a type of bottle having approximately the following dimensions: height over all, 223.5 millimeters; length of graduated part of neck, 139 millimeters; diameter of graduated part of neck, 9.07 millimeters.

As already stated, some of the centrifuges in common use will not hold a bottle more than 6 inches long. It therefore seemed necessary to develop a bottle of such dimensions that it would fit the 6-inch centrifuge. This could be accomplished either by shortening the neck and increasing its diameter, and so keeping the size of the sample at 9 grams, or by reducing the size of the sample, which would allow both shortening the neck and reducing its diameter. In a 6-inch bottle the graduated part of the neck is limited to approximately 93.5 millimeters, which means that for a 9-gram sample the diameter must be 11.07 millimeters. Since the most satisfactory results are not obtained in cases in which the diameter of the neck exceeds 9.5 millimeters, it seemed best to cut the size of the sample to a point where a bottle with a neck approaching this diameter could be

used. This was attained in the 6-inch, 6-gram, 90-per-cent butter bottle of the following dimensions: height over all, 165.09 millimeters; length of graduated part of neck, 93.5 millimeters; diameter of graduated part of neck, 9.04 millimeters.

Several bottles of the 6-inch, 5-gram, 90-per-cent type were made for this investigation, but since the possibility of error was increased thru the use of a smaller sample, without materially improving the graduations, the results of the 5-gram bottle are not presented here.

Taking the sample

A discussion of any method of analysis of butter should include some facts concerning practical methods for sampling the product. Commercially this feature is a most vital one, and a disregard of these facts may lead to very erroneous results. Butter in the tub, in any finished package, or even in the churn, is not a homogeneous mass, and in this condition, unlike milk or cream, it cannot be readily mixed or stirred. The difficulty of securing representative samples from such packages has been shown by Guthrie and Ross (1913) and by Lee, Hepburn, and Barnhart (1909). It is noticeable that more uniform and representative samples can be obtained from the over-worked butter usually found in the manufacturing plants of Illinois than from medium or under-worked butter.

Sampling from the churn.— Since butter as found in the churn is not homogeneous even after the washing process is completed (Guthrie and Ross, 1913), any effort to secure a representative sample must necessarily result in a sample which approximates the composition of the total mass rather than one which actually represents it. Creamery control samples are usually taken from the churn by the following method: the surface of the butter for the full length of the churn is first removed with a ladle; then, by means of a spatula or a spoon, at least ten samples are transferred from points about equally distributed between the two ends of the churn, to make up the composite sample in a 5- to 8-ounce glass-stoppered bottle. It is obvious that the greater the number of small samples and the larger the composite, the more likely the composite is to represent accurately the butter in question.

Sampling from the tub.— Securing an accurate sample of butter from the tub is even more difficult than getting one from the churn. Many methods

ι suggested for obtaining representative composites, but any one methods may under certain conditions result in considerable

In sampling butter in this condition, it is usually desirable to sample in such a manner that the original neat appearance of age will be maintained. For this purpose the ordinary butter-thod is generally used. Usually two triers, spaced about equi-rom the center of the tub, are drawn, representing the full depth ıb. These samples are then transferred to the glass container ıttle loss of moisture as possible.

Preparing the sample for analysis

ıing that the sample under observation has been collected in the ›ppered bottle just previous to analysis, it is placed in a warming ere it is held until the butter assumes a semi-liquid condition. ıg should be accompanied by frequent shaking. In this condition ter constituents may separate, and the problem is to get them back complete mixture approaching emulsion. This is accomplished by ıal cooling of the sample, accompanied by almost constant and vig-ıgitation. When the mixture has reached a condition approaching ısistency of very thick cream, it is in proper condition for sampling ılysis.

›cond method of preparing the sample is by the use of a mechanical . This method is frequently employed in commercial plants, where is a considerable factor in the determination.

Making the test with the 9-inch, 9-gram, 90-per-cent bottle

ıen the butter has attained the consistency described above, a 9-gram le is weighed into the butter bottle. This transfer to the test bottle d be made by pouring directly rather than by the use of a pipette. ıle as sensitive as that commonly used for moisture testing in butter .d be used.

ıe sample having been weighed into the test bottle, 9 cubic centi-ırs of lukewarm water is added, followed by 17.6 cubic centimeters of mercial sulfuric acid. Extreme care must be exercised in adding the because of the violent reaction which frequently takes place between acid and the salt in the butter, causing foaming and occasionally the

loss of the sample. To avoid this difficulty the acid should be added in small portions, and mixed thoroly after each addition, until finally the 17.6 cubic centimeters has been added. After the sample has been thoroly mixed with the acid, water is added in sufficient quantity to fill the bottle to the base of the neck. (It is obvious that less than 17.6 cubic centimeters of acid would dissolve all the solids in butter; one distinct advantage of adding a larger amount of acid, however, is that it is desirable to have considerable liquid of high specific gravity in the test bottle to insure a more complete separation of the fat.) The bottle is then placed in the tester and centrifuged for a period of five minutes at the same rate of speed that is used in testing milk and cream. Water is then added to bring the fat up within the graduated part of the neck, and the sample is centrifuged for four minutes.

Reading the test.— Samples are transferred from the tester to a reading bath and tempered at from 125° to 130° F. The best results are obtained by removing the meniscus with glymol (Hunziker and others, 1910). The results are read directly in terms of percentage of butterfat.

Making the test with the 6-inch, 6-gram, 90-per-cent bottle

The preceding directions for testing with the 9-inch, 9-gram, 90-per-cent bottle are followed in detail with the 6-inch, 6-gram, 90-per-cent bottle with two changes; first, 6 grams instead of 9 grams of butter are weighed with the test bottle; secondly, 12 cubic centimeters of water is added just previous to the introduction of the acid.

RESULTS OF THE EXPERIMENT

The reliability of this method of testing is shown by a comparison of the results obtained thru its use with the results obtained by chemical analyses on the same samples. The samples of butter under consideration were tested in the 9-inch, 9-gram bottle and the 6-inch, 6-gram bottle by the author, after which they were given to another operator who performed similar tests on the same samples. These samples are characterized in the data as original and check samples, respectively. All results were finally compared with the chemical analyses.[3] The results are presented in the form of direct comparison and also in the form of correlation tables.

[3] The ch[illegible] were made by J. M Barnhart and Dr. E. F Kohman, dairy chemists, Agricultural C[illegible] of Illinois. They were made according to the indirect official method as described [illegible] the United States Bureau of Chemistry.

The results of the work of two operators on the same sample of butter, compared with the results obtained by a chemist on the same sample, are given in table 2:

TABLE 2. RESULTS OF THE MODIFIED BABCOCK METHOD COMPARED DIRECTLY WITH RESULTS OBTAINED BY CHEMICAL ANALYSIS

(Expressed in percentage of butterfat)

Test no.	6-gm. 6-in. (N. W. H.)	9-gm. 9-in. (N. W. H.)	9-gm. 9-in. (L. R. L.)	9-gm. 9-in. (L. R. L.)	6-gm. 6-in. (L. R. L.)	Chemical analysis
1	79 75	80 00	79 50	79.50	79 50	78 74
2	82 50	83 00	82 75	82.50	83.00	82 56
3	80 00	80 00	80 00	79 50	80.00	79 95
4	85 50	85.50	85.50	85 25	85.00	85.08
5	83.50	83 50	83 00	83.50	83.00	82 50
6	84.50	84.50	81 50	84 50	84.50	84.50
7	84 00	84.50	83.50	83.50	84.00	84 00
8	82.50	82 50	82 50	83.00	83.00	83.00
9	82 50	82 50	82.50	82.50	83.00	83.00
10	84 50	84.50	85.50	85 00	85.00	85.00
11	83 00	....	84 25	84 00	83.50	83.75
12	83 00	....	83.50	84.00	83.50	83.37
13	78 50	....	78.50	79.50	78.50	78.57
14	80 50	....	81.00	81.00	80 75	81 19
15	75.50	....	75 50	75.50	75.50	75 47
16	82.50	82 75	82 50	83.00	....	81.98
17	82 00	82 00	82 00	81.50	....	80.86
18	83 50	83 25	83 00	83.25	....	82 61
19	82 50	82 25	83 00	82 50	....	82.51
20	83.25	83 50	83 50	83 00	....	82 88
21	80 50	80 50	80 75	....	80 50	81 08
22	76 00	76 25	76 25	....	76 25	76 25
23	80 00	80 00	80 00	....	80 00	80.60
24	79 50	79.50	79 50	....	79.50	79.68
25	82 50	82 25	82 25	....	82 00	82 06
26	81 75	81 75	81 50	....	81 50	80 09
27	81.50	82 00	80 00	....	81 50	80 85
28	79 25	79 00	79 00	....	78.00	78 39
29	80 00	80 25	80 00	....	80 00	80.33
30	80 00	81 00	79 50	....	79 50	80.36
31	80 50	80 25	80 25	....	80 50	80 68
32	81.75	81 50	81 50	....	81 50	81.21
33	83 00	83 00	82 50		82 25	82 87
34	80 50	80 50	80 50	.	81 00	81 17
35	82 50	82 25	82 25		82 00	82 06
36	78 60	78 80	78 50	..	78 75	78 77
37	81 25	81 50	81 25	..	81.75	81.67
38	85 00	85 00	....	....	....	85.26
39	84.50	84.00	....	....	....	84.60

TABLE 2. RESULTS OF THE MODIFIED BABCOCK METHOD COMPARED DIRECTLY WITH RESULTS OBTAINED BY CHEMICAL ANALYSIS (*continued*)

(Expressed in percentage of butterfat)

Test no.	6-gm. 6-in. (N. W. H.)	9-gm. 9-in. (N. W. H.)	9-gm. 9-in. (L. R. L.)	9-gm. 9-in. (L. R. L.)	6-gm. 6-in. (L. R. L.)	Chemical analysis
40	79 50	79 60	...	...	...	80 00
41	82.00	82 00	...	...	...	82 18
42	76.25	76 50	...	...	...	76 29
43	80 50	80 50	...	...	...	80 24
44	...	83 25	83 50	...	...	83 22
45	84 50	84 50	84 50	...	84 50	84 64
46	84.00	84 50	83 50	...	84 00	84.16
47	82 50	82 50	82 50	...	83 00	82 40
48	82 50	82 50	82 50	...	83 00	82 40
49	84 50	84 50	85 50	...	85 00	84 66
50	85 00	85 25	85 00	...	84 50	84 87
51	83 00	83 00	82 50	...	83 00	82 83
52	79 75	79 00	79 75	...	80 00	79 73
53	85 50	85 00	85 50	...	85 25	86 66
54	82.50	83 00	82 50	...	83 00	82 34
55	84 25	83 50	83 00	...	83 00	83 60
56	85 00	85 25	85 00	...	84 50	84 79
57	82 50	82 50	82 00	...	82 00	81.97
58	83 00	83 50	84 00	...	84 00	83 32
59	82 00	82 00	82 50	...	83 00	82 39
60	80 00	79.75	77.75	...	...	77 68
61	...	83 50	...	...	...	83 95
62	85 50	85 50	85 75	...	...	86 00
63	82 50	85.50	...	...	...	82 93
64	82 00	...	82 50	...	...	82.80
65	...	...	82 50	...	...	81 93
66		...	83 00	...	...	82.12
67	...	...	83.00	...	82 50	81 69
68	...	...	82 50	...	82 50	82 09
69	...		83.00	...	83 00	82 00
70	...	...	82 00	...	81 50	81 63
71	...	...	82 00	...	81 50	81 73
72	...	...	82 25	...	81 50	81 69
73	82 00	...	82 50	...	81 75	81 83
74	81.75	81 25	82 50	...	82 50	81 49
75	...	81 00	82 00	...	81.50	81 55
76	81.00	81.50	81 50	...	81.50	81 06
77	80.50	80 00	...	...	80 50	80.36
78	80 50	81 00	81 50	...	81 00	80 36
79	81.00	80 50	81 00	...	80 50	80 30
80	81 50	81 50	81 25	...	81 25	80 99
81	81 50	82 00	...	...	...	81 76
82	82 00	82 25	82 00	...	81 50	80 70
83	81.50	81.25	81.50	...	81.00	80.61

TABLE 2. RESULTS OF THE MODIFIED BABCOCK METHOD COMPARED DIRECTLY WITH RESULTS OBTAINED BY CHEMICAL ANALYSIS (*concluded*)

(Expressed in percentage of butterfat)

Test no.	6-gm. 6-in. (N. W. H.)	9-gm. 9-in. (N. W. H.)	9-gm. 9-in. (L. R. L.)	9-gm. 9-in. (L. R. L.)	6-gm. 6-in. (L. R. L.)	Chemical analysis
84	80 00	80 50	.....	....	....	78.82
85	84 50	84 00	.....	....	....	83 98
86	78 50	78 50	.	....	....	77.82
87	82 00	82 50	..	.....	....	81.46
88	80 50	80 25	. .	......	....	80.42
89	81 00	81 00	....	....	....	81.84
90	82.00	82 00	....	....	....	82 30
91	82 00	81.75	....	....	....	82.91
92	82 00	82 50	....	....	....	82.22
93	79 00	79.00	....	....	....	79.07
94	85 00	84 50	....	....	....	85.09
95	79 00	79 50	....	....	....	79.17
96	81.50	81.50	....	....	....	80 80
97	81 50	82 00	....	....	....	81.25
98	83.50	83 25	....	....	....	83.69
99	83 25	83.25	....	....	....	83.26
100	83.00	83 50	.....	......	....	82 13
101	80.50	81.50	....	....	....	81 79
102	81.50	82.00	....	....	....	80 40
103	80 50	80.75	....	......	....	79 47
104	84 50	84.00	..	....	......	83.64
105	83 50	83 50	....	....	....	84 08
106	81 25	82 00	. .	.....	.....	80 65
107	81 00	81 00	...	.....	.....	81 39
108	82 00	82 75	...	....	....	81 45
109	81 50	82 00	...	.....	.....	81 65
110	79 50	..	....	.....	.....	79.45
111	80 75	81 50	...	....	....	79 68
112	83 00	83 50	......	....	....	83 50
113	83 00	83 50	...	......	....	83.52
114	80 00	81 00	.	.....	.....	81.03
115	83 50	82 75	..	..	......	82.47
116	82 00	82.50	...	...	......	82.57
117	79 50	79 50	....	...	....	80.69
118	82 00	82.50	...	.....	.....	82.42
119	......	82 00	82.00	81.75	82 00	82.02
120	......	78 00	78.00	78 00	78 00	78 33
121	.....	85 25	85 25	85 00	85.25	84 99
122	....	80 00	80 00	80 00	....	80.48
123	......	80 00 79 50	79 75 80.00	80 00	79 50	80 21
124	.....	79 50 79.75	79 50	79.50 79 75	79.50	80.25

The performance of the above described tests, as well as chemical analyses on the same 124[4] samples of butter, has resulted in considerable data from which an estimate of the relative accuracy of these tests may be obtained. In order to get some mathematical expression with which to show how nearly the results from the two methods are in agreement, certain statistical methods involving correlation coefficients are applied. The mathematical expressions employed in this work have already been used to a considerable extent in agricultural literature, for the purpose of presenting the results of rather complicated statistical investigation (Davenport 1907, Davenport and Rietz 1907, Rietz and Smith 1910).

The data for each type of bottle, including both original and check tests, are tabulated also in the form of separate correlation tables. These correlation tables may be regarded as double-entry tables in which the data are classified with respect to both chemical analyses and modified Babcock tests. As an illustration of the meaning of the figures in the correlation tables, the number *2* in the fourth row, third column, of table 3 means that there are two cases out of 124 in which the result of the chemical analysis falls within the interval 78–78.9 and the corresponding result for the modified Babcock test falls within the interval 79–79.9.

The correlation tables representing, respectively, the various methods under discussion, together with the checks, exhibit the original data from which are derived the mathematical expressions denoting the merits of the modified Babcock method. These expressions are the mean, designated by m; the coefficient of correlation, designated by r; the standard deviation, designated by t; and the coefficient of variability, designated by C. Since the coefficient of correlation in general may be understood as the numerical measure of the interrelations between different characters, it may be used in this instance as an expression to indicate how closely the results obtained by the modified Babcock method follow the results obtained by chemical analysis.

The first comparison considered is that of the results of the modified Babcock test using 6-inch, 6-gram bottles, with the results obtained from chemical analysis (table 3). When these tests are applied to the same

[4] Comparisons on more than double this number of samples were made at various times, but in presenting the data by the statistical method only those in which the data a[illegible] with reference to the 9-inch, 9-gram, and the 6-inch, 6-gram, checks and chemical analyses, [illegible]

TABLE 3. CORRELATION BETWEEN PERCENTAGE OF BUTTERFAT OBTAINED BY CHEMICAL ANALYSIS, SUBJECT, AND PERCENTAGE OF BUTTERFAT BY THE MODIFIED BABCOCK TEST, RELATIVE. SIX-INCH, SIX-GRAM BOTTLES

	76–76.9	77–77.9	78–78.9	79–79.9	80–80.9	81–81.9	82–82.9	83–83.9	84–84.9	85–85.9	86–86.9	
76–76.9	2											2
77–77.9		1										1
78–78.9		1	4									5
79–79.9			2	6	3							11
80–80.9		1	1	3	11	6						22
81–81.9					6	11	1					18
82–82.9					3	3	17	4				27
83–83.9							8	10	2			20
84–84.9								3	5	1		9
85–85.9							1		2	1	2	9
	2	3	7	9	23	20	27	17	9	5	2	124

124 samples of butter, the means and variabilities for and the correlations between the chemical analysis and the 6-inch, 6-gram analysis are as follows:

Babcock test	Chemical analysis
m = 81.91 ± .12	m = 81.72 ± .12
t = 1.97 ± .08	t = 2.02 ± .09
C = 2.41 ± .11	C = 2.47 ± .11

r = .935 ± .008

The mean percentage of butterfat in all the samples by chemical analysis is found to be 81.72 ± .12, while by the modified Babcock method (6-inch, 6-gram bottles) it is 81.91 ± .12. This is a difference of 0.19 per cent in the means. Since the probable error of each of the means, 0.12, is nearly as great as the difference between the means, no significant difference is shown to exist between the means of the results from each method. The standard deviations, 2.02 ± .09 for the chemical analysis and 1.97 ± .08 for the 6-inch, 6-gram analysis, show no significant difference, as is also the case with the coefficients of variability, 2.47 ± .11 for the chemical analysis and 2.41 ± .11 for the 6-inch, 6-gram bottle. The fact that these two measures of variability exhibit no significant differences is still further evidence that the two methods of analysis yield results which are almost identical and are for all practical purposes interchangeable.

To determine the correlation between individual results from chemical analyses and those obtained from the modified Babcock method, the correlation coefficient, r, is employed. This coefficient is a number whose value is not greater than 1 nor less than −1. A perfect positive correlation is given by $r = 1$, no correlation by $r = 0$, and a perfect negative correlation by $r = -1$. The correlation coefficient for the data in table 3, representing 124 samples, is $0.935 \pm .008$. Since this is a very high degree of correlation, the evidence is positive that the two methods of analysis yield results almost identical.

An examination of table 3 itself throws further light on the agreement of these results. It will be observed that the numbers arrange themselves very close to a diagonal running from the upper left corner to the lower right corner. If the results of the modified Babcock method and those of chemical analysis had been in exact agreement, the numbers would fall exactly on such a diagonal. The fact that they fall so close to this diagonal indicates that a high degree of correlation exists. Taking as a basis an assigned interval of 1 per cent in the tabulation of the results from the chemical analysis, it is seen that the variation in the modified Babcock test is confined to a very narrow limit. Out of a total of 124 comparisons, the two sets of results differ by 0.5 per cent or less in 78 cases, by 1 per cent or less in 113 cases, and by less than 2 per cent in 123 cases.

TABLE 4. CORRELATION BETWEEN PERCENTAGE OF BUTTERFAT OBTAINED BY CHEMICAL ANALYSIS, SUBJECT, AND PERCENTAGE OF BUTTERFAT BY THE MODIFIED BABCOCK TEST, RELATIVE. NINE-INCH, NINE-GRAM BOTTLES

	76–76.9	77–77.9	78–78 9	79–79.9	80–80 9	81–81.9	82–82 9	83–83 9	84–84.9	85–85.9	86–86 9	
76–76 9	2											2
77–77 9		1										1
78–78 9		1	2									3
79–79 9		1	2	4	3							10
80–80 9			3	1	10	3						17
81–81 9				1	5	11	1					18
82–82 9					6	8	12	2				28
83–83 9							11	8	1			20
84–84 9								4	5	2		11
85–85.9									2	3	2	7
	2	3	7	6	24	22	24	14	8	5	2	117

The correlation between the results from the modified Babcock test using 9-inch, 9-gram bottles, and the results from chemical analysis, is shown in table 4. The means and variabilities for and the correlation between these results are as follows:

Babcock test		Chemical analysis
m = 82.04 ± .12		m = 81.68 ± .13
t = 1.91 ± .08		t = 2.03 ± .09
C = 2.33 ± .10		C = 2.49 ± .11
	r = .918 ± .010	

A difference of 0.36 ± .17 is found to exist between the two means. This difference, while small, indicates a possible tendency for the 9-inch, 9-gram bottles to yield results slightly higher than those from the chemical analysis. The difference is not great enough, however, in the light of the probable error, to be regarded as significant. The two measures of variability also point to a very close agreement between the results of the two methods of analysis.

The data in table 4, like those in table 3, tend toward an arrangement in a diagonal of rather narrow limits. Mathematically the correlation is 0.918 ± .010. In 73 cases the results obtained by the modified Babcock method with the 9-inch, 9-gram bottles differ from those of chemical analysis by less than 0.5 per cent; in 99 cases the difference is less than 1 per cent; in 111 cases it is less than 1.5 per cent; and in 117 cases it is less than 2 per cent. On the basis of the data obtained, the two methods may be considered as yielding results which are for practical purposes identical.

Comparing the correlation coefficient for the results obtained with the 6-inch, 6-gram bottles and chemical analysis (0.935 ± .008) with the correlation coefficient for the results with the 9-inch, 9-gram bottles and chemical analysis (0.918 ± .010), it may be noted that there is a difference of 0.017 ± .013 between the two correlations.

It will be remembered that check tests were made by having the same samples tested by another operator. The relation existing between such checks and the originals when 6-inch, 6-gram bottles were used is shown

TABLE 5. CORRELATION BETWEEN PERCENTAGES OF BUTTERFAT OBTAINED RESPECTIVELY BY TWO OPERATORS APPLYING THE MODIFIED BABCOCK TEST WITH SIX-INCH, SIX-GRAM BOTTLES TO THE SAME SAMPLES OF BUTTER. CHECK TESTS, SUBJECT; ORIGINAL TESTS, RELATIVE

	76–76.9	77–77.9	78–78.9	79–79.9	80–80.9	81–81.9	82–82.9	83–83.9	84–84.9	85–85.9	
76–76 9	1										1
77–77 9											0
78–78 9			4								4
79–79 9			1	3							4
80–80 9				1	10	2					13
81–81 9					1	8	2				11
82–82 9						2	2	5			9
83–83 9							1	5			6
84–84 9									4	2	6
85–85.9										3	3
	1	0	5	4	11	12	5	10	4	5	57

in table 5. The means and variabilities for and the correlations between these results are as follows:

Original tests	Check tests
$m = 81.68 \pm .18$	$m = 81.77 \pm .19$
$t = 1.97 \pm .12$	$t = 2.10 \pm .13$
$C = 2.41 \pm .15$	$C = 2.57 \pm .16$

$$r = .973 \pm .005$$

In this case the two means show a difference of 0.09, which is approximately one-half the probable error of either mean. Consequently the means may be said to show no significant difference and for practical purposes may be considered identical. The standard deviations and the coefficients of variability, which are the measures of variability, also show no significant differences.

There is a somewhat higher degree of correlation between the results of the 6-inch, 6-gram original and check tests (table 5) than between the results of the 6-inch, 6-gram test and the chemical analysis (table 3). The figures for the former tend to fall into relatively small assigned classes, and form an almost perfect diagonal from the upper left to the lower right of the table. For the comparison of 6-inch, 6-gram originals with 6-inch, 6-gram checks, the correlation coefficient is $0.973 \pm .005$; while

for the comparison of 6-inch, 6-gram originals with the chemical analysis, the correlation coefficient is 0.935 ± .008. This is a difference of 0.038 ± .009. These results would seem to indicate that a closer agreement exists between the results of duplicates on the 6-inch, 6-gram bottles than between the results of the modified Babcock test with 6-inch, 6-gram bottles and the chemical analysis.

TABLE 6. CORRELATION BETWEEN PERCENTAGES OF BUTTERFAT OBTAINED RESPECTIVELY BY TWO OPERATORS APPLYING THE MODIFIED BABCOCK TEST WITH NINE-INCH, NINE-GRAM BOTTLES TO THE SAME SAMPLES OF BUTTER. CHECK TESTS, SUBJECT; ORIGINAL TESTS, RELATIVE

	76–76.9	77–77.9	78–78.9	79–79.9	80–80.9	81–81.9	82–82.9	83–83.9	84–84.9	85–85.9	
76–76.9	2										2
77–77.9		1									1
78–78.9			2								2
79–79.9			1	3							4
80–80.9				3	8	1					12
81–81.9				1		8	2				11
82–82.9					1		14	2			17
83–83.9							3	9	1		13
84–84.9								3	4	1	8
85–85.9										7	7
	2	1	3	7	9	9	19	14	5	8	77

The comparative results on check and original tests when 9-inch, 9-gram bottles are used are shown in table 6. The means and variabilities for and the correlations between these results are as follows:

Original tests	Check tests
$m = 82.16 \pm .16$	$m = 82.07 \pm .16$
$t = 2.06 \pm .11$	$t = 2.13 \pm .12$
$C = 2.51 \pm .14$	$C = 2.50 \pm .14$

$$r = .964 \pm .005$$

The means for the original and the check tests with the 9-inch, 9-gram bottles also show no significant difference. The same is true of the standard deviations and the coefficients of variability.

The correlation coefficient for the data presented in table 6 is 0.964 ± .005. This coefficient, like that representing the comparisons with checks in the case of the 6-inch, 6-gram samples (table 5), indicates a

very high degree of correlation. Evidence of close checking is further substantiated by the fact that there is no significant difference in the means, the standard deviations, or the coefficients of variability. As previously shown, the coefficient of correlation between results of the modified Babcock test with 9-inch, 9-gram bottles and chemical analysis is 0.918 ± .010 (table 4), and that for the 9-inch, 9-gram originals and checks is 0.964 ± .005, a difference of 0.046 ± .011. This difference indicates that there is a higher degree of correlation between the original and the check tests than between the results of the modified Babcock test with the 9-inch, 9-gram original and the chemical analysis. It will be remembered that an analogous result was obtained in the case of the 6-inch, 6-gram bottles.

With the 9-inch, 9-gram bottles, about the same degree of accuracy is shown in the duplicates as that existing in the case of the 6-inch, 6-gram bottles. The results shown in table 6 emphasize the possibility of securing good checks when duplicate determinations are made by different operators. This, it should be noted, is a more difficult kind of check than that of duplicate determinations by the same operator.

The foregoing data show the close relationship that exists between the results obtained from comparisons of the modified Babcock test for 6-inch, 6-gram bottles with chemical analysis, and of the modified Babcock

TABLE 7. CORRELATION BETWEEN PERCENTAGES OF BUTTERFAT OBTAINED BY APPLYING THE MODIFIED BABCOCK TEST WITH SIX-INCH, SIX-GRAM BOTTLES (SUBJECT) AND WITH NINE-INCH, NINE-GRAM BOTTLES (RELATIVE) TO THE SAME SAMPLES OF BUTTER

	76–76 9	77–77 9	78–78 9	79–79 9	80–80 9	81–81.9	82–82 9	83–83.9	84–84.9	85–85 9	
76–76 9	2										2
77–77 9		1									1
78–78 9			3	1							4
79–79 9				7	3						10
80–80 9				2	13	6					21
81–81 9					1	11	7				19
82–82 9						1	21	3			25
83–83 9								16	2		18
84–84.9								1	8		9
85–85.9									1	7	8
	2	1	3	10	17	18	28	20	11	7	117

test for 9-inch, 9-gram bottles with chemical analysis. Interesting comparisons may be made also between the results obtained with the 6-inch, 6-gram bottle and those obtained with the 9-inch, 9-gram bottle. Such comparisons are presented in table 7. The means and variabilities for and the correlation between these results are as follows:

Six-inch, six-gram bottles	Nine-inch, nine-gram bottles
$m = 81.90 \pm .12$	$m = 82.04 \pm .12$
$t = 1.95 \pm .09$	$t = 1.91 \pm .08$
$C = 2.38 \pm .004$	$C = 2.33 \pm .10$

$$r = .966 \pm .004$$

These data show that there is about the same degree of accuracy wher samples are tested with 9-inch, 9-gram bottles as exists when the same samples are tested with 6-inch, 6-gram bottles. From the operator's point of view, however, the 9-inch, 9-gram bottle is preferable since it is more easily read and manipulated.

APPLICATION OF THE RESULTS

Checking plant operations

Urged by the increased pressure of a more aggressive competition, plant managers and manufacturers are realizing anew the importance of accurate plant checks for the purpose of controlling inefficiency and losses in manufacture. Within the plant there are three possible points of check on butterfat. The first of these occurs when the cream comes into the plant, at which time a determination is made of the total butterfat received. The second occurs when the cream is assembled in the ripeners. It is obvious that at this point the total butterfat in the ripeners should equal the sum of all butterfat paid for by the plant for any given period, minus any reasonable losses occasioned by the handling and pasteurizing processes. The third and last opportunity for a check, and one that is usually overlooked, is at the point when the butter is collected in the churn just previous to being packed. A fat determination at this point will yield a result representing the total butterfat recovered in the butter; that is, the total number of pounds of butter in the churn multiplied by its fat percentage will represent the total fat recovered

in the butter, and this figure should check with the ripener determination for fat for a given amount of cream, and in turn with the fat purchased for that churning.

Such checks were made at the University of Illinois creamery for a period of one year, and some of the typical results are here presented to illustrate the practicability of such a system of plant-check records. The figures

TABLE 8. RESULTS OF CREAMERY PLANT CHECKS

Check no.	Fat bought (pounds)	Fat in ripener (pounds)	Butter (pounds)	Fat recovered in butter	
				Per cent	Pounds
1	333 1	337 4	421	80 00	336 6
2	316.7	314.6	377	82 50	311 0
3	445 1	440 2	545	80 00	436.0
4	327 0	324 0	408	81.00	325 6
5	208 6	203.4	255	82.50	210 3
6	307 0	309 6	375	82 50	309.0
7	327 0	321 0	395	81 75	323.9
8	247 7	247 3	310	80 00	248.0

(table 8) are suggestive of the possibility that exists for making more complete plant check records. This system is followed to some extent at the present time in some of the larger manufacturing plants of the United States.

Legal considerations

The legal regulations under which butter manufacturers now operate are given in an Act of Congress dated August 2, 1886, Section 1, as follows:

> Butter defined: that for the purpose of this Act, the word butter shall be understood to be the food usually known as butter, and which is made exclusively from milk or cream or both, with or without common salt, with or without the addition of coloring matter.

Butter is further defined by an Act of Congress, approved May 9, 1902, as

> the clean, non-rancid product made by gathering in any manner the fat of fresh or ripened milk or cream into a mass, which also contains a small portion of the other milk constituents, with or without salt, and contains not less than eighty-two and five-tenths (82.5) per cent of milk fat.

The following paragraph is taken from page 87 of Regulations No. 9, revised July, 1907, United States Internal Revenue:

> The definition of adulterated butter as contained in the Act of May 9, 1902, embraces butter in the manufacture of which any process or material is used whereby the product is made to contain abnormal quantities of water, milk, or cream; but the normal content of moisture permissible is not fixed by the act. This being the case it becomes necessary to adopt a standard for moisture in butter, which shall in effect represent the normal quantity. It is, therefore, held that butter having 16 per cent or more of moisture contains an abnormal quantity and is classed as adulterated butter.

The paragraphs just quoted constitute the essentials of the regulations under which butter manufacturers now operate. The fat standard of 82.5 per cent, however, has never been enforced. This has left in operation the ruling of the Internal Revenue Department demanding in substance that butter containing more than 16 per cent of moisture be considered adulterated. This has been the manufacturer's working basis for more than fifteen years, and it is just now coming to be realized that this enforced ruling in many ways does not fulfill all the requirements for a standard. Serious consideration has been given both by the law makers and by the manufacturers to the question of changing this ruling, and the most representative expression of these bodies at this time seems to be that placing a maximum on one of the nonessential ingredients in butter does not adequately control the product, either by way of protecting the consumer or by way of protecting the manufacturer from unjust competition. The sentiment at the present time, therefore, seems to favor a minimum legal fat content of 80 per cent in butter. If this ruling is put into effect, a new demand is at once created for a method of quickly determining fat in butter.

SUMMARY

The securing of a representative sample is one of the most important, as well as one of the most difficult, factors in making butter analyses.

Consistent duplicates and accurate results can be obtained only when a system of careful preparation of the sample is followed.

In a modified Babcock method of butter analyses, the test bottles should be so constructed that readings for percentage of fat are made directly.

In this investigation the 9-inch, 9-gram, 90-per-cent bottles and the 6-inch, 6-gram, 90-per-cent bottles were found to be the most satisfactory

types. From the standpoint of manipulation, the 9-inch, 9-gram bottle, permitting of a larger sample and better-spaced graduation, is the more desirable of these two.

The method of testing butter for fat, outlined in the text, yields results on the 124 samples which correspond very closely with those obtained by chemical analysis.

There was practically no difference between the results obtained with the 9-inch, 9-gram, 90-per-cent bottle and those obtained with the 6-inch, 6-gram, 90-per-cent bottle.

Check tests made by independent operators yield results which correspond more closely with each other than do the results on the respective bottles with chemical analyses.

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THE CARBON DIOXIDE OF THE SOIL AIR

H. W. TURPIN

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CONTENTS

THE CARBON DIOXIDE OF THE SOIL AIR

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H. W. TURPIN

Carbonic acid has long been recognized as an important soil solvent. On this point, at least, authorities are well agreed, but from the data available it is not yet clear what factors are most important in controlling the production of carbon dioxide in the soil. It is generally conceded, however, that a large proportion of the carbon dioxide found is due to soil microorganisms. The significance of plant roots in this connection has been recognized by some investigators, while others appear to be not quite decided as to how important plant-root excretions are.

HISTORICAL REVIEW

IMPORTANCE OF THE CARBON DIOXIDE IN THE SOIL

That carbon dioxide in solution is an important soil solvent has been shown by Stoklasa and Ernest (1909).[1] These workers point out that when ground gneiss and basalt are mixed with nutrient solutions, the amount of phosphorus and potassium absorbed by the plants grown is directly proportional to the carbon dioxide produced per gram of dry matter of the roots.

Aberson (1910) concluded, as a result of studies with young plants, that, while the excretions from plant roots may not be sufficiently concentrated (in carbon dioxide) to have a marked effect in dissolving insoluble materials, still the mucilaginous covering of the root hairs, containing a saturated solution of carbon dioxide, is entirely sufficient to bring into solution the insoluble soil constituents with which it comes in contact, especially the phosphates.

The limited usefulness, as a solvent, of the carbon dioxide secreted by plant roots is pointed out by Pfeiffer and Blanck (1912), who show that in soils treated with phosphates the carbon dioxide given off by plant roots is not a sufficient solvent to account for all the mineral nutrients obtained by the plant from the soil.

[1] Data in parenthesis refer to *Bibliography*, page 349.

Besides its importance as a direct solvent in the soil, carbon dioxide has considerable significance as an indicator of certain soil activities. Hutchinson (1912) observed a relationship between the biological activities and the amount of carbon dioxide in the soil. Russell (1915, a and b) noticed a close parallelism between the carbon-dioxide and the nitrate production in the soil, there being more of these constituents in spring and fall than in midsummer and winter. It was pointed out later by Russell and Appleyard (1915) that the curves for the bacterial numbers, the nitrate production, and the carbon-dioxide content in the soil thruout the season, show marked similarity, indicating that the carbon dioxide may serve to some extent as an indicator of other soil activities. Neller (1918), however, could find in his experiments no correlation between the ammonia production and the carbon dioxide formed, except in cases in which he used pure cultures of bacteria. The lack of correlation he attributed to the predominating influence of fungi in the soil.

In addition to its importance as a direct solvent in the soil and as an indicator of certain soil activities, carbonic acid may possibly be significant as an inhibitor of the activity of soil organisms and perhaps even of plant growth. Large quantities of carbon dioxide in the air have been found by numerous investigators to be detrimental to the growth of the higher plants. E. Wollny (1897) observed an increased production of carbon dioxide with an increase in the organic matter in the soil, but the increase to the unit of organic matter was less with the larger application. This Wollny attributed to the inhibiting effect of carbon dioxide on the bacterial activities. The work of Plummer (1916), however, showed that exceedingly large amounts of carbon dioxide do not interfere with the activities of the ammonifying and nitrifying organisms, provided, in the latter case, that the oxygen supply is not reduced below a certain minimum. The same investigator showed that the maximum carbon-dioxide production in the soil corresponds with the point of maximum nitrification. In studies on the carbon dioxide produced in lysimeter tanks, Bizzell and Lyon (1918) noted a marked decrease in the production of this gas after the blooming period of an oat crop on Dunkirk clay loam. This decrease, they say, "was apparently due to the depressing effect of the crop on production by bacterial action." Such a decrease was not found to take place on a Volusia silt loam.

FACTORS AFFECTING THE AMOUNT OF CARBON DIOXIDE IN THE SOIL AIR

Soil organisms

Most investigators consider that soil organisms play a large part in the production of carbon dioxide in the soil. Pettenkofer (1858, 1871, 1873, 1875) concluded, as a result of his investigations, that most of the carbon dioxide in the soil is due to living organisms.

Later, E. Wollny (1880b) found that there is only a small production of carbon dioxide in an atmosphere of hydrogen gas, while chloroform almost completely stops the power of the soil to form carbon dioxide. He concluded that carbon dioxide is produced largely by bacteria.

Further confirmation of this is to be found in the studies of Dehérain and Demoussy (1896), which showed that sterile soil at a temperature of 22° C. produces only insignificant amounts of carbon dioxide. Stoklasa and Ernest (1905), after working with beets, clover, oats, and other plants, noted that a bare soil produced, in one hundred and fifty days, more than twice the carbon dioxide produced by a crop of wheat on the same area in sixty days. They observed also a correlation between the numbers of bacteria and the carbon dioxide produced at different depths in the soil. Hutchinson (1912) concluded that carbon-dioxide production is a reliable measure of bacterial activity.

Soil conditions

Where soil conditions are favorable to the action of bacteria, the carbon-dioxide content is usually high. For example, Stoklasa (1911) obtained the greatest production of this gas in a soil that was well aerated, slightly alkaline, and well supplied with readily available plant nutrients. This was found by E. Wollny (1897), Russell and Appleyard (1915), and others, to be especially true in the case of soils having readily available organic matter. Very small amounts of carbon dioxide were found in the swamp rice lands of India by Harrison and Aiyer (1913), showing that unfavorable soil conditions are associated with a low content of carbon dioxide.

Seasonal conditions

Russell and Appleyard (1915, 1917) emphasized the importance of seasonal conditions on the carbon-dioxide content of the soil. In their investigations they observed that a rise of temperature is accompanied

by an increase in carbon dioxide. The same fact had been previously noted by Möller (quoted by E. Wollny, 1880a), by Dehérain and Demoussy (1896), by Stoklasa and Ernest (1905), and by Leather (1915), and was later mentioned by Potter and Snyder (1916).

Carbon-dioxide production was found by the Rothamsted investigators (Russell and Appleyard, 1917) to be correlated with moisture and rainfall. Previously E. Wollny (1880a) had observed that increasing amounts of water up to 9 per cent, in a quartz sand mixed with peat, resulted in an increase in the carbon dioxide. Dehérain and Demoussy (1896) found that there was an optimum water content for carbon-dioxide production in a garden soil. Van Suchtelen (1910) found the greatest amount of carbon dioxide when the soil with which he worked was 75 per cent saturated with water.

The relationship observed by Russell and Appleyard (1917) between the rainfall of the preceding week and the carbon-dioxide content of the soil, was believed by them to be due largely to the oxygen dissolved in the rain water. That this may be true is shown by the earlier work of E. Wollny (1897), and also by that of Fodor (1875), who showed that there is a relationship between the carbon-dioxide content and the oxygen of the soil, indicating that the carbon dioxide is probably produced by oxidation processes.

The crop

The evidence available thus seems to point to bacteria as the chief source of soil carbon-dioxide. There are some data, however, which show that plants may play a considerable part in the production of this gas in the soil.

Stoklasa and Ernest (1909) and Aberson (1910) noted that the roots of plants excrete large amounts of carbon dioxide. That the gas so formed is not insignificant is proved by the fact that field studies conducted at Rothamsted by Russell and Appleyard (1917) showed a considerably higher content of carbon dioxide in cropped soil than appeared in the bare soil, this being especially marked in May, at the time of the most active growth of the plant, and at the time of ripening. The same condition was observed by Bizzell and Lyon (1918) in the case of an oat crop on Dunkirk clay loam, where the greatest production of carbon dioxide took place at about the time of blooming. Potter and Snyder (1916) observed

similar results with timothy, but they were unable to decide whether or not this increase of carbon dioxide was due to the plant-root excretions or to the decay of root particles that had died during the growth of the crop. The work of Stoklasa and Ernest (1905) showed that the younger the plant is, the greater is the amount of carbon dioxide formed. Kossowitch (1904) noted that mustard grown in quartz sand and nutrient solutions produced an increased amount of carbon dioxide up to the time of blooming. This was observed also by Barakov (1910) in the case of plants growing in lysimeters.

That different kinds of plants produce different amounts of carbon dioxide has been shown by Lau (1906), who found that potatoes and legumes give off more carbon dioxide than do other crops. Red clover, beets (*Beta vulgaris*), and oats were found by Stoklasa and Ernest (1905) to produce more carbon dioxide than other plants, and in the order named. Russell and Appleyard (1915), however, could find no difference in the carbon-dioxide content of soils on which different species of plants were growing.

Chemical factors

From the brief survey given, it would seem correct to say that most of the carbon dioxide found in the soil is the result of biological activity. There is some evidence, however, showing that chemical action may play a small part. E. Wollny (1880 b) noted a very slight production of carbon dioxide in soil treated with chloroform. The same investigator demonstrated later (E. Wollny, 1897) that organic matter in the absence of oxygen reduces manganese and iron oxides and forms carbon dioxide. Very little carbon-dioxide production in sterilized soil kept at a temperature of 22° C. was observed by Dehérain and Demoussy (1896). They found, however, a very considerable production of carbon dioxide in soil heated to 90° C. and above. An oxidizing enzyme in the excretions of the root hairs was considered by Molisch (1888) to be capable of producing carbon dioxide from organic substances. It is probable that carbon dioxide produced by chemical means forms an extremely small part of the total carbon dioxide found in the soil.

Summary

In this review of the literature of the subject, certain facts stand out. Authorities are agreed that bacteria play an important part, probably

the most important part of all the factors concerned, in the production of carbon dioxide in the soil. Climatic factors, such as temperature, rainfall, and air supply, have a marked effect on the carbon-dioxide content of the soil. Crops increase the amount of carbon dioxide in the soil, either by direct excretions from the roots or thru the decay of root particles from the growing crop. Finally, the nature of the soil itself causes marked differences in the production of carbon dioxide.

The results reported in this paper confirm some of the above conclusions, but they also show that the influence of the crop has been underemphasized.

EXPERIMENTAL WORK

In the author's first experiment, a study was made for two seasons (1917 and 1918) in the greenhouse, with soil cropped to oats and with uncropped soil. The object was to try to establish some definite relationship between the carbon dioxide in a cropped soil and that in an uncropped soil, where the crop itself introduced the only variable. Such a relationship having been established, it was decided to determine in the second experiment whether or not it would hold for a different crop. The third experiment was designed to analyze the factors concerned in the production of carbon dioxide, and, if possible, to assign to each its respective part.

EXPERIMENT 1

The cylinders illustrated in figure 44 were used in the first experiment. These cylinders, eight in number, were made of galvanized iron, coated inside with a layer of paint to insure their being air-tight at the joints and to prevent rusting. They were 3 feet high by 1 foot in diameter, and each had a cone-shaped bottom leading to the cocks on the outside as indicated in figure 45.

The cone-shaped bottom was filled with gravel, above which was placed a 12-inch layer of soil from the second foot of the field soil. Above this was placed a foot of surface soil. The soil used was Dunkirk clay loam. The moisture in the soil was maintained thruout the course of the experiment at 30 per cent on the oven-dry basis. The soil was covered with a half-inch layer of quartz sand in order to reduce the evaporation, the sand being added to the cropped soil immediately after seeding. The dry weight of the soil in each of the cans was 94.3 pounds.

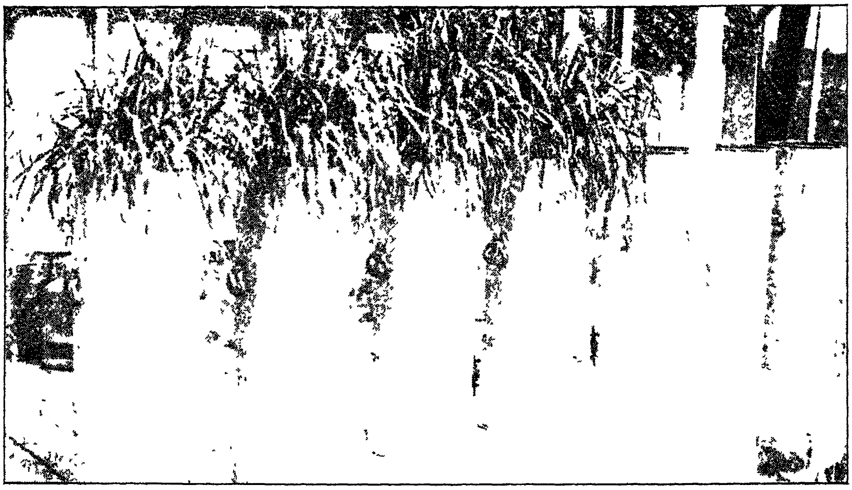

FIG 44. CANS USED IN FIRST EXPERIMENT

The four cans at the left contain an oat crop, which is shown at the period of its growth a month before the maximum amount of carbon dioxide was found in the air of the cropped soil

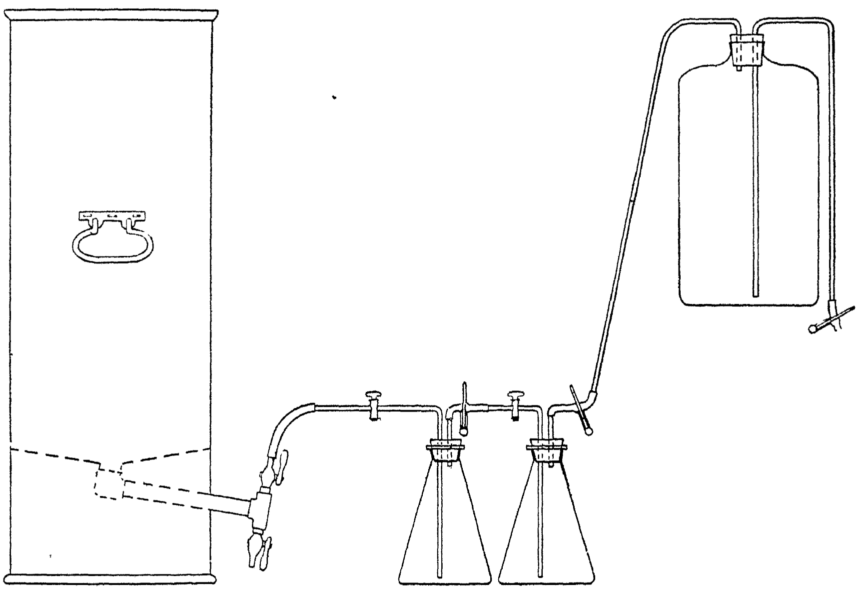

FIG. 45. ARRANGEMENT OF CYLINDER, SAMPLING FLASKS, AND ASPIRATOR

Before seeding, some preliminary studies were made in order to ascertain the best method of obtaining the sample of soil air for analysis. It seemed impracticable to use any method other than one that could be carried out rapidly, since it was planned to run the test for two seasons and to take the samples twice each week thruout the year. As a result of the preliminary studies, it was found that by aspirating four liters of air thru the soil cans in five minutes, and passing the air thru two graduated 500-cubic-centimeter Erlenmeyer flasks, samples could be obtained in the two flasks which checked with each other, indicating that the air originally present in the flasks had been replaced by a representative sample of the air in the soil. If more or less than four liters was aspirated thru the soil, the amounts of carbon dioxide in the two flasks did not check, indicating, in the first case, that the original air in the soil had been replaced by air from the atmosphere and that some of the latter was passing into the flasks, and in the second case that the original air in the flasks had not been completely replaced in the flask nearer the aspirator. The method of sampling is shown in figure 45. After the aspiration was completed, the cocks on the flasks were closed and the flasks were removed to the headhouse, where they were allowed to reach room temperature. The excess pressure in the flasks was relieved by opening one of the cocks for a moment. The temperature was noted at this point, as all calculations were reduced to per cent by volume of carbon dioxide at standard atmospheric conditions, that is, 760 millimeters pressure and 0° C.

Excess of standard barium hydroxide was next run into the flasks. The volume of the barium hydroxide added was noted, and was subtracted from the total volume of the flask. The cocks were then closed, and the flasks were allowed to stand, with occasional vigorous shaking, for about thirty minutes, after which the excess barium hydroxide was determined by titrating with standard oxalic acid whose equivalent in terms of carbon dioxide had been previously determined by titrating with standard potassium permanganate solution.

The method of aspirating air thru the soil has been criticized by Potter and Snyder (1916) in a paper describing experiments in which they determined the carbon dioxide evolved by drawing a current of air continuously over the soil surface. They maintain that the occasional drawing of air thru the soil will result in a temporary decrease in the content of carbon dioxide, which, however, will soon be restored by the

activities of the soil, and this accumulation of carbon dioxide will, by the mass action law, finally result in a retardation of further production of the gas. On the other hand, they maintain that by drawing a current of air continuously over the surface of the soil, conditions more nearly similar to those obtaining in the field will result. This may be true for experiments conducted in a quiet room; but in the greenhouse, where there is a circulation of air, there is ample opportunity for diffusion to take place from the soil, especially where, as in these experiments, one of the lower cocks of the soil can was always left open, so that a sample taken at any particular time should be truly representative of the carbon dioxide actually present under normal conditions.

It has been pointed out by Leather (1915) that usually only about 25 per cent of the carbon dioxide in the soil is in the gaseous state, the remainder being dissolved in water. It is reasonable to suppose that, once the soil water is saturated with this gas, any further production of carbon dioxide will tend to increase the content in the soil air. Considering these facts, then, it will be seen that the method used in these tests will not give, and was not intended to give, absolute amounts of carbon dioxide; but it nevertheless should yield reliable relative values.

On April 2, 1917, the soil, which is a heavy clay loam rich in silt and having a lime requirement of about 3000 pounds to the acre (Veitch), was brought up to 30 per cent moisture content on the oven-dry basis. Four of the cans were seeded to White Russian oats. A half-inch layer of quartz sand was then spread over the surface of the soil in the eight cans.

From April 12 to September 28 the samples were taken twice a week. From September 29 the sampling was done approximately once in two weeks until February 7, 1918, after which date the samples were again taken twice a week. The second crop of oats was planted on January 9. Some fifty seeds were usually sown, and the plants were thinned out in the course of two weeks to fifteen in each can. In the season of 1917, one plant became infected with smut, and on June 13 this plant was removed, together with one plant from each of the other cans. To maintain the moisture content of the cropped cans at 30 per cent (oven-dry basis) frequent waterings were necessary, especially at the time of most vigorous growth. At that period the cropped cans were irrigated once a day. The amount of water added was recorded in order to see whether or not there was any relationship between the transpiration and the carbon-

dioxide production in the cropped soil. Since only about a quarter of a pound of water was lost in a week from the uncropped soil, tap water was used in all cases, as the small loss by evaporation could not possibly introduce a disturbing element in the form of an accumulation of soluble salts in the soil.

Results

On each date of sampling, the samples were taken in duplicate from each of the eight cans. Thus eight samples were obtained from the cropped soil and eight from the bare soil. Since all of the four cropped cans were treated in identically the same manner, the data for the duplicate samples from the cropped cans were averaged. This was done also in the case of the bare soil.

It seemed fair to average the data obtained from the cans in each set because in all cases the differences were small. This is shown by the very small probable error. The data for the oat crops of 1917 and 1918 are given in tables 1 and 2 (appendix, pages 353 to 356), each figure for carbon dioxide in these two tables being the average of eight determinations. These summarized results are represented diagrammatically in figures 46 and 47.

Effect of crop

The content of carbon dioxide at the beginning of the experiment was 0.28 per cent by volume for both cropped and uncropped soil. From that time on, as may be seen from figures 46 and 47, the amount of carbon dioxide in the uncropped soil in no case reached that in the cropped soil — not even after the removal of the crop. The latter point may perhaps be explained by the fact that since the roots of the crop were not removed from the soil at harvesting, they somewhat increased the available supply of organic matter. The results reported here are directly opposite to those of Bizzell and Lyon (1918), who worked with the same Dunkirk clay loam under field conditions and found that subsequent to the removal of the oat crop a marked decrease in carbon dioxide below that in the uncropped soil took place. This was not found to be the case, however, with the Volusia silt loam used by these investigators.

A study of figure 46 shows that in the season of 1917 there was a marked increase in the carbon dioxide in the cropped soil from the beginning of May, a month after seeding, until the maximum, 2 per cent, was reached

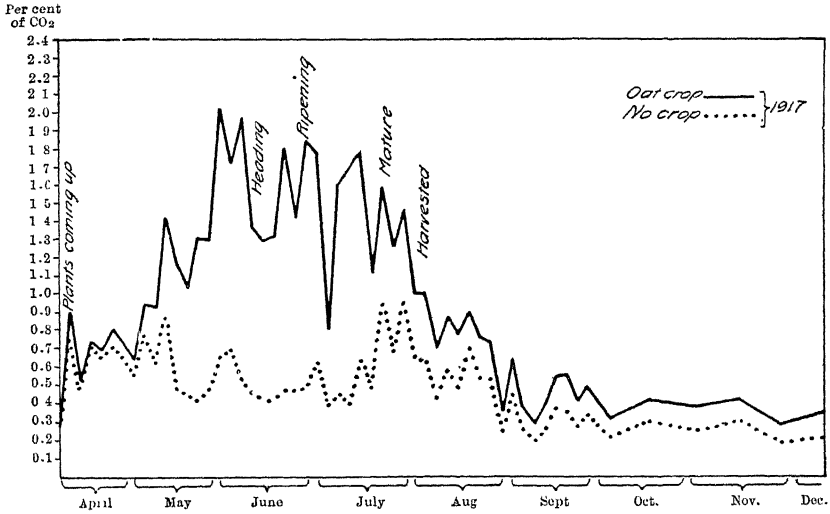

FIG. 46. CARBON DIOXIDE IN AIR FROM DUNKIRK CLAY LOAM CROPPED TO OATS AND FROM THE SAME SOIL LEFT BARE, 1917

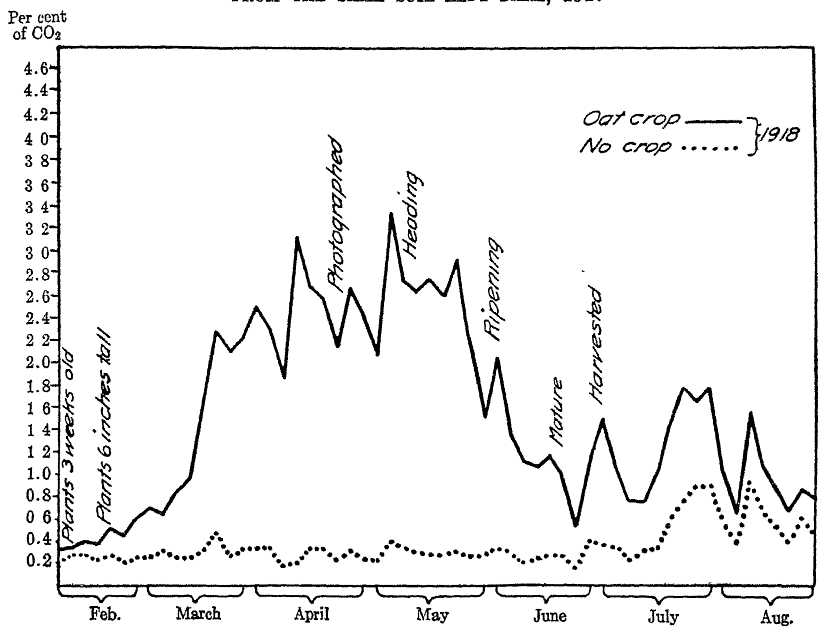

FIG. 47. CARBON DIOXIDE IN AIR FROM DUNKIRK CLAY LOAM CROPPED TO OATS AND FROM THE SAME SOIL LEFT BARE, 1918

in the first week of June, at the time when the plants were starting to head. Thereafter the general tendency of the curve for the cropped soil was toward a decrease, altho it was not until the middle of July, two weeks previous to harvesting, that this decrease was very marked. It was pointed out by Russell and Appleyard (1917) that in their experiments a large increase in carbon dioxide was observed in the cropped soil at the time of ripening; but, as can be seen from figures 46 and 47, in neither 1917 nor 1918 was any such increase noted in this work. If anything, the ripening was accompanied by a marked decrease in carbon dioxide, as is shown especially for the season of 1918 (fig. 47). Subsequent to the removal of the crop, the carbon dioxide in the cropped soil continued to decrease, but never to a point below or equal to that in the uncropped soil.

It is interesting to note that in 1917, fluctuations in the content of carbon dioxide in the uncropped soil were accompanied by similar variations in the cropped soil during the early part of the season and subsequent to harvesting. This was not true during the period of active growth of the plant, which would seem to indicate that at that time the life activity of the crop itself, rather than that of the soil organisms, is playing the dominant part in controlling the production of carbon dioxide.

What has been said for the season of 1917 holds for 1918 also. During the latter season, however, there was a much more marked increase in the carbon dioxide of the cropped soil. By the 11th of April, three months after seeding, more than 3 per cent of carbon dioxide was found, as compared with a little less than 0.2 per cent in the uncropped soil. This occurred four weeks previous to heading. Thereafter the content of carbon dioxide in the cropped soil increased to the maximum of 3.34 per cent, which occurred a week before heading and coincident with the time of rapid elongation of the culms. Following the maximum there was a steady decline. The decrease was especially marked during early June, when the upper glumes were beginning to turn yellow and the plants were starting to mature. In figure 44 (page 325) the plants are shown a month before the period of maximum carbon-dioxide production.

Since the maximum of 3.34 per cent of carbon dioxide found in the soil was about the same as that noted by Bizzell and Lyon (1918) in their studies with Dunkirk clay loam cropped to oats, it is evident that the decrease in the production of carbon dioxide in the cropped soil below

that in the uncropped soil after the removal of the crop, reported by these investigators, may not be due to interference with bacterial activities, since in the work reported in the present paper no such action on the soil organisms, as evidenced by a decrease in carbon-dioxide production, was observed. It may be possible that the decrease noted by Bizzell and Lyon was due to some other effect of the crop, such as, for example, the reduction of the soil moisture. It has been pointed out in the review of the literature of the subject that some investigators have noted a decrease in carbon dioxide where the moisture was reduced below a certain optimum amount. On referring to figure 46 it will be seen that early in July, 1917, the carbon dioxide in the cropped soil showed a marked decrease. This was due to the drying-out of the soil when, thru an oversight, it was not watered for two days.

It has been pointed out that the carbon dioxide in the cropped soil was somewhat higher (about 30 per cent) in 1918 than it was in 1917. The results for the two seasons are not strictly comparable, because in 1917 the crop was sown in April whereas in 1918 the seeding was made in January. Also, in 1917 the number of plants was reduced to fourteen in each pot, while in 1918 there were fifteen. However, the total dry weight of the mature crop from the four cans in 1917 was 494.5 grams, as against 416 grams in 1918.

Carbon-dioxide and water relationships

As has already been stated, a record was kept of the amount of water added to the cropped cans in order to maintain them at a moisture content of 30 per cent (oven-dry basis). The sand mulch on the soil, as has been pointed out also, was so effective that the loss in moisture on the cropped cans could be regarded as due entirely to transpiration.

The total amount of water lost on the cropped cans each week was determined in 1917 and 1918 for a period of ten weeks during which the crop was making the most active growth. These amounts, together with the average weekly content of carbon dioxide in the cropped and the uncropped soil, are indicated in tables 3 and 4 (appendix, pages 357 to 358), columns A, C, and E. The difference between the carbon dioxide in the cropped and that in the uncropped soil is given in column F of the same tables. The carbon dioxide produced to each pound of water used is shown in columns G and H. The figures in column G were obtained

by dividing the weekly carbon-dioxide percentage in the cropped soil after the carbon dioxide in the bare soil had been subtracted, by the weekly loss of water in pounds. The figures in column H, however, were obtained by dividing the weekly carbon-dioxide percentage in the cropped soil by the weekly loss of water without first subtracting the carbon dioxide in the bare soil from that in the cropped soil.

The relationship between the carbon dioxide produced in the cropped soil (from which has been subtracted the carbon dioxide in the bare soil), and the water transpired by the crop, is shown graphically in figures 48 and 49. There seems to be a relationship between the amount of water transpired and the carbon dioxide produced by plants, as is indicated

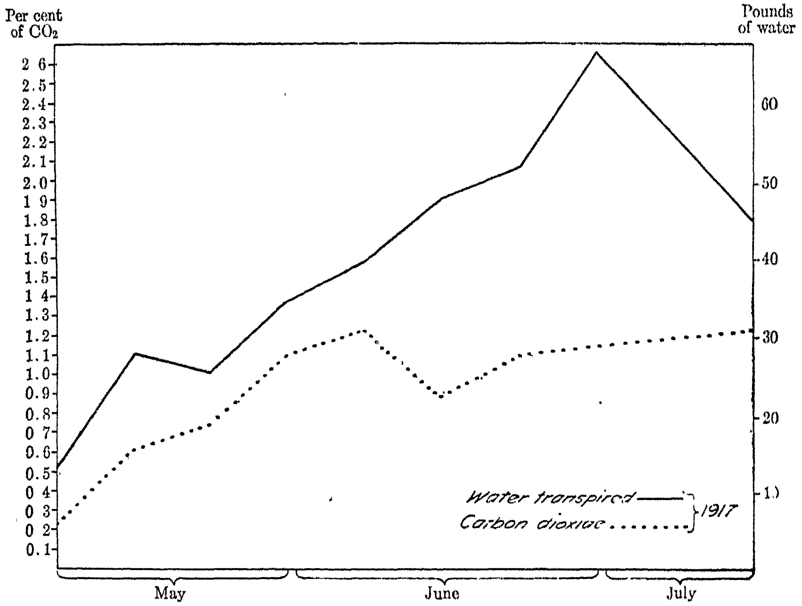

FIG. 48. RELATION BETWEEN WATER TRANSPIRED AND CARBON DIOXIDE PRODUCED BY AN OAT CROP FOR THE TEN WEEKS DURING WHICH ITS GROWTH WAS MOST VIGOROUS, 1917

by tables 3 and 4 and by figures 48 and 49. The illustrations show that the curves for the water transpired each week, and for the carbon dioxide obtained by subtracting the carbon dioxide in the bare soil from that in the cropped soil, follow each other closely. The data given in the

tables and plotted in the curves are for the period of ten weeks during which the plants were growing most actively. Before and after this period no relationship was found to exist between the amount of water transpired and the carbon dioxide produced by the plants.

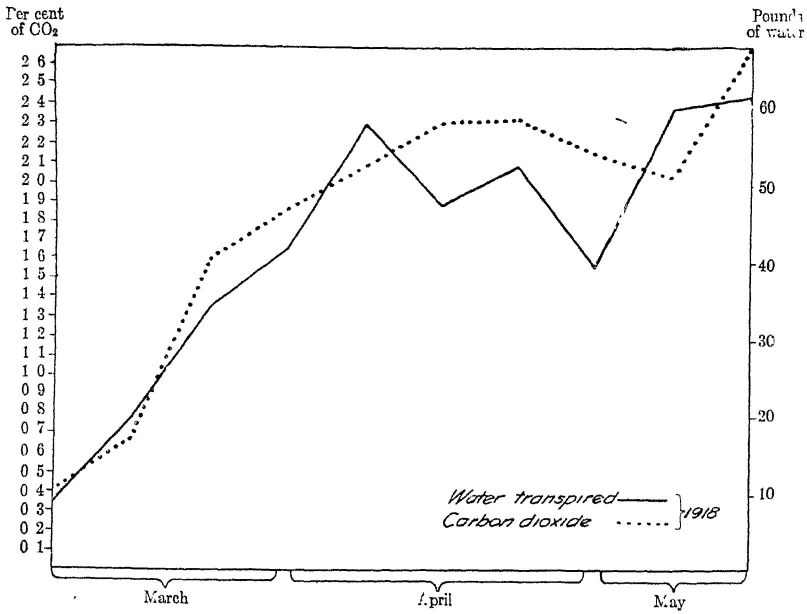

FIG. 49. RELATION BETWEEN WATER TRANSPIRED AND CARBON DIOXIDE PRODUCED BY AN OAT CROP FOR THE TEN WEEKS DURING WHICH ITS GROWTH WAS MOST VIGOROUS, 1918

It is seen in columns G and H of tables 3 and 4 that the percentage of carbon dioxide produced to each pound of water transpired, approaches a constant much more nearly when the carbon dioxide in the uncropped soil is subtracted from that in the cropped soil. The smaller coefficients of variability of 22.5 ± 3.74 as compared with 37.4 ± 5.65 in 1917, and 15.1 ± 2.32 as against 19.17 ± 3.12 in 1918, bring out this fact fairly clearly. If it is assumed that the amount of carbon dioxide produced and the amount of water transpired are indications of life activity, then the relationships found between the carbon dioxide in the soil, and the water transpired, would hold only when the carbon dioxide is produced

by the crop alone. When the carbon dioxide in the uncropped soil was subtracted from the carbon dioxide found in the cropped soil, and this figure was divided by the amount of water transpired, there resulted approximately a constant of 0.024 $\pm$ .0012 (column G) with a coefficient of variability of 22.5 $\pm$ 3.74 for 1917, and a constant of 0.043 $\pm$ .0014 with a coefficient of variability of 15.1 $\pm$ 2.32 for 1918. When the carbon dioxide in the uncropped soil, which may be attributed to bacterial activity, was not subtracted (column H), there resulted a constant of 0.042 $\pm$ .0031 with a coefficient of variability of 37.4 $\pm$ 5.65 for 1917, and a constant of 0.053 $\pm$ .0022 with a coefficient of variability of 19.17 $\pm$ 3.12 for 1918.

This shows that the constants in the latter cases are not nearly so dependable as those in the former, indicating that the carbon dioxide produced by the crop is probably the difference between the carbon dioxide in the cropped soil and that in the bare soil. That the values obtained are not perfect constants can hardly be wondered at when it is recalled that the carbon dioxide as determined was not absolute, but relative.

In this connection it may be pointed out that there seems to be some ground for concluding that there is a relationship between the water transpired by the plant and the carbon-dioxide content of the soil.

While it is not disputed that the mechanism by which the water is actually lost from the leaves of the plant is purely physical and not at all associated with vital plant activity, yet the process by which the water is brought into the leaves and into a condition to be transpired may well be considered as being associated with the life activities of the plant. Many investigators have maintained that there is a distinct relationship between the life activities of plants and the water transpired. For example, as early as 1849 Lawes (1850) considered that the comparative rate of transpiration of water to some extent indicated the relative activity of the processes of the plant. He drew these conclusions from studies with wheat, barley, beans, peas, and clover, in which he compared the amount of ash and dry matter obtained from the plants with the water given off by them. He found that the larger the amount of dry matter, the greater was the quantity of water transpired. These views are supported by the investigations of Sorauer (1878, 1880), but the work of Walter Wollny (1898) leads to an opposite conclusion. In 1905 Livingston (1905) worked with wheat seedlings and concluded that total transpiration is as good a criterion for comparing the relative growth of plants in

different media as is the weight of the plant itself. Hasselbring (1914), however, after growing plants under cheesecloth and in the open, stated that the mere passage of water thru the plant had no influence on the assimilatory activity of the plant, provided the water supply did not fall below a certain minimum required to maintain turgor of the cells. Stoklasa and Ernest (1909) determined the carbon dioxide given off by different plants grown in various nutrient solutions, and obtained the results presented in table 5 (appendix, page 358). These figures show that there is a definite relationship between the total dry weight of different crops and the carbon dioxide produced. The average of 0.037 milligram of carbon dioxide to each milligram of dry matter seems to be independent of the kind of plant used in the test.

From the short review given, it would seem that the evidence is in favor of the assumption that transpiration is related to life activity of plants as indicated by a relationship between the dry matter and the water transpired. The work of Stoklasa and Ernest (1909) would point to a correlation between the carbon dioxide produced and the dry matter in the plant.

Effect of temperature and atmospheric pressure

The relationship between the temperature and the atmospheric pressure at the time of sampling, and the carbon dioxide in the air of the uncropped soil, is shown graphically in figures 50 and 51 for the seasons of 1917 and 1918, respectively. The temperature at each time of sampling was found to be approximately representative of the temperature for the preceding twelve-hours period. The pressure also would probably represent the average of several hours preceding the sampling.

On the whole the figures bring out only a few striking facts. High temperatures were usually accompanied by a high percentage of carbon dioxide, while high atmospheric pressures were usually associated with a low carbon-dioxide content. High pressures along with high temperatures gave fairly high contents of carbon dioxide, indicating that temperature has a more marked effect than pressure. When the temperature and the pressure were medium there appeared to be no relationship with the carbon-dioxide content. Very low temperatures were always accompanied by a low content of carbon dioxide; but, while a very low pressure did not necessarily mean a high carbon-dioxide content, it was usually associated with such a condition.

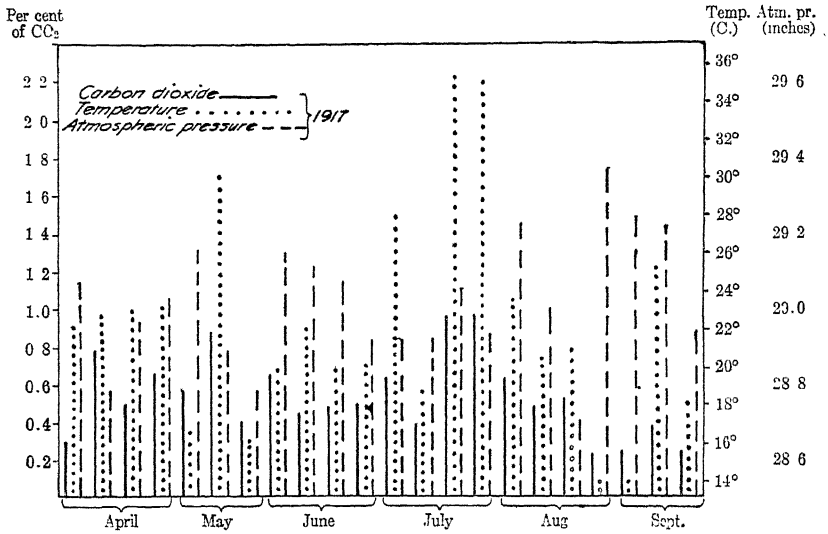

FIG. 50. RELATION BETWEEN THE TEMPERATURE OF THE SOIL AT THE TIME OF SAMPLING, THE ATMOSPHERIC PRESSURE, AND THE CARBON DIOXIDE IN THE AIR OF THE UNCROPPED SOIL, 1917

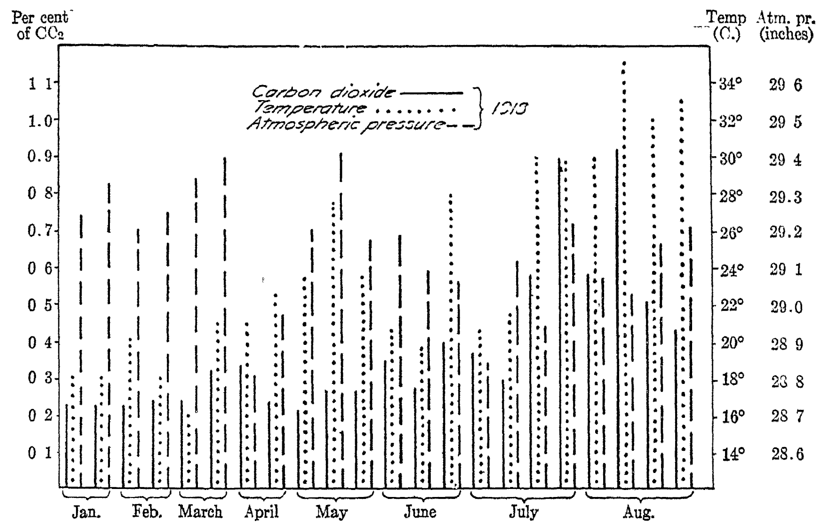

FIG. 51. RELATION BETWEEN THE TEMPERATURE OF THE SOIL AT THE TIME OF SAMPLING, THE ATMOSPHERIC PRESSURE, AND THE CARBON DIOXIDE IN THE AIR OF THE UNCROPPED SOIL, 1918

Summary of experiment 1

The results of the first experiment may be summarized as follows:

1. Soils cropped to oats always contained a greater amount of carbon dioxide than did the corresponding bare soils.

2. The crop had a residual effect, increasing the carbon-dioxide content above that in the uncropped soil.

3. The difference between the amount of carbon dioxide in the cropped soil and that in the uncropped soil at the period of most active crop growth, divided by the amount of water transpired by the crop, gave an apparent constant which varied with the season.

4. The fact just stated may indicate that the difference between the amount of carbon dioxide produced in the cropped soil and that in the uncropped soil represented the amount produced by the crop.

5. It is thus evident that the carbon dioxide from plants and from soil organisms accumulated independently.

6. Fluctuations in the amount of carbon dioxide in the uncropped soil were due largely to temperature and pressure variations. High pressures produced low contents of carbon dioxide, while high temperatures caused high production of carbon dioxide, and vice versa.

EXPERIMENT 2

The object of the second experiment was to determine the influence of some crop other than oats on the production of carbon dioxide. The crop used in this case was common millet (*Setaria italica*).

Immediately after the harvesting of the 1918 oat crop, millet was planted on the same soil and in the same cylinders as were used in experiment 1. For experiment 2 the surface layer of sand was entirely removed from the soil, which was then thoroly stirred to a depth of about three inches. The millet was seeded on four of the soils, of which two had previously been in oats and two had been bare. The object in using these two different sets was to try to produce some differences in the two crops of millet. It was thought that possibly the millet growing on the soil which had been previously cropped twice to oats, might not grow well, and in such a case a comparison could be made between a good and a poor crop of millet.

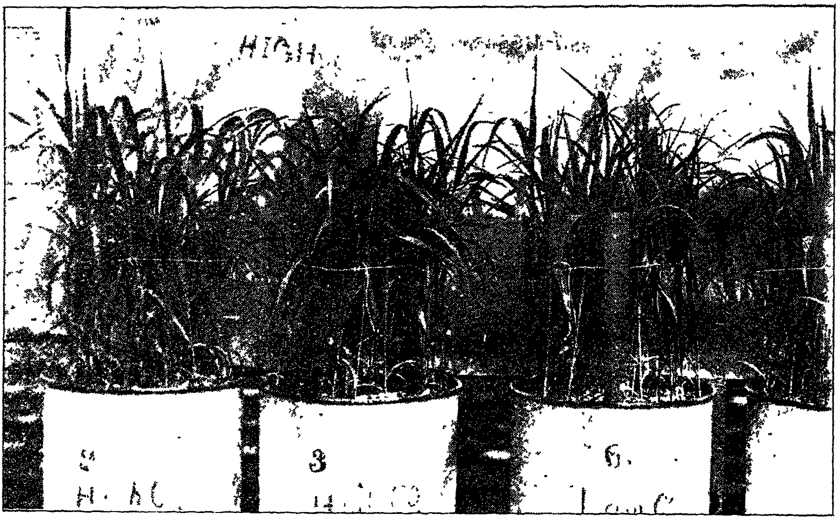

FIG. 52. MILLET CROPS SIX WEEKS AFTER SEEDING, ON THE TWO SOILS HAVING HIGH AND LOW INITIAL CONTENTS OF CARBON DIOXIDE, RESPECTIVELY

Close view, showing details

The crop was planted on July 1. Within three weeks after planting, the crop on each can had been thinned out until forty plants remained. The number of plants to a pot was reduced in the next week to thirty. At first the samples were taken twice a week, as in the case of experiment 1; but later — from the middle of August — when the crop was making very rapid growth, samples were taken every day. Toward the end of August the samples were taken every other day. As in experiment 1, the moisture in the soil was maintained at 30 per cent (oven-dry basis).

At the time when the experiment was discontinued, the plants were completely headed. In the case of series 1 (soil previously cropped to oats) the plants were beginning to show signs of maturing; in series 2 (soil previously bare), however, the grain was still between the milk stage and the dough stage.

The crops on series 1 and 2 were identical in all details until a few days after heading. This may be seen in figures 52 to 55. Thereafter the plants in series 2 maintained their dark green color, while those in

FIG. 53. MILLET CROPS SIX WEEKS AFTER SEEDING, ON THE TWO SOILS HAVING HIGH AND LOW INITIAL CONTENTS OF CARBON DIOXIDE, RESPECTIVELY

Same as figure 52, but showing cylinders

series 1 gradually became light green, until finally, when the experiment was stopped in September, the latter were beginning to mature while those in series 2 had not yet begun to show signs of ripening.

Results

The results of experiment 2 are summarized in table 6 (appendix, page 359), in which each figure represents the average of two duplicate samplings from each of two pots, an average of four samplings in all.

FIG. 54. MILLET CROPS SEVEN AND ONE-HALF WEEKS AFTER SEEDING, ON THE TWO SOILS HAVING HIGH AND LOW INITIAL CONTENTS OF CARBON DIOXIDE, RESPECTIVELY

Close view, showing details

These data are presented diagrammatically in figures 56, 57, and 58, the first two representing the data for series 1 and 2, respectively, and the third giving these two sets of curves on one sheet.

It will be noticed that the carbon dioxide in the cropped soils and that in the uncropped soils remained the same for the first four weeks after seeding. Thereafter the curves for the cropped soils separated fairly rapidly from those for the bare soils. In this respect there is no difference between the oats and the millet. It will be observed, however, that whereas the two oat crops attained their point of maximum carbon-dioxide production shortly before heading, the millet crops both gave the most carbon dioxide just ten days after heading. In order to bring out this point more clearly, curves showing the relationship between the amount of carbon dioxide in the oat soil (1917) and that in the millet soil (series 2) have been plotted together in figure 59, in such a manner that the carbon dioxide produced at the period of heading of each of the two crops is on the same ordinate, with the data for a few weeks

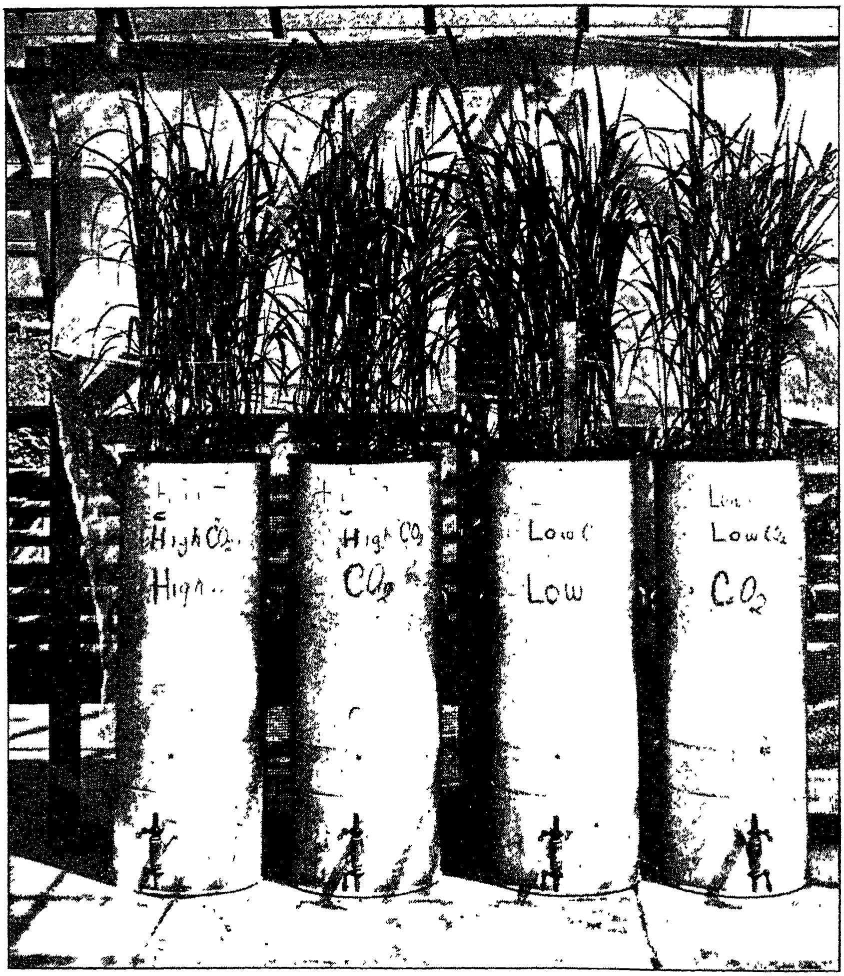

FIG. 55. MILLET CROPS SEVEN AND ONE-HALF WEEKS AFTER SEEDING, ON THE TWO SOILS HAVING HIGH AND LOW INITIAL CONTENTS OF CARBON DIOXIDE, RESPECTIVELY

Same as figure 54, but showing cylinders

before and a few weeks after the heading period plotted to the left and to the right of this point, respectively.

Since the experiment was discontinued before the millet crops matured, it is not possible to say whether or not the curve for the later period of

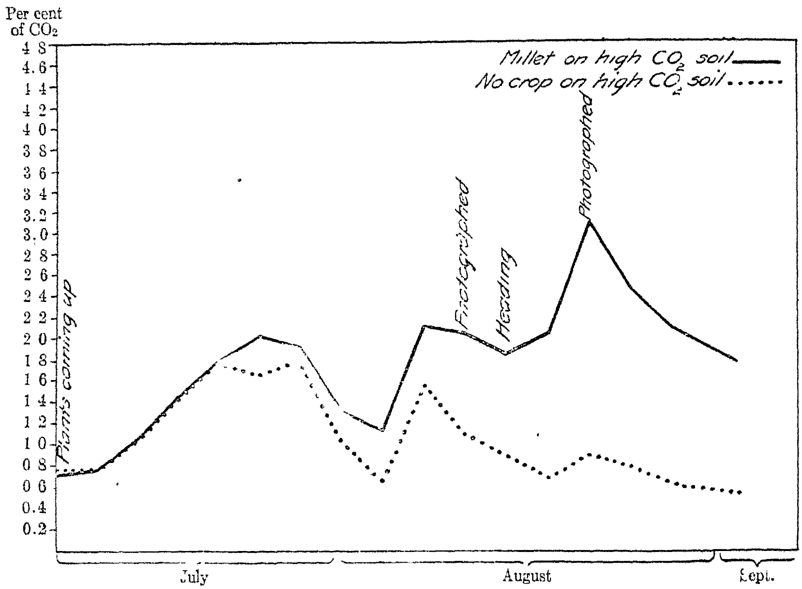

FIG. 56. CARBON DIOXIDE IN AIR FROM DUNKIRK CLAY LOAM PREVIOUSLY CROPPED TWICE TO OATS, CROPPED TO MILLET, AND FROM THE SAME SOIL LEFT BARE, 1918

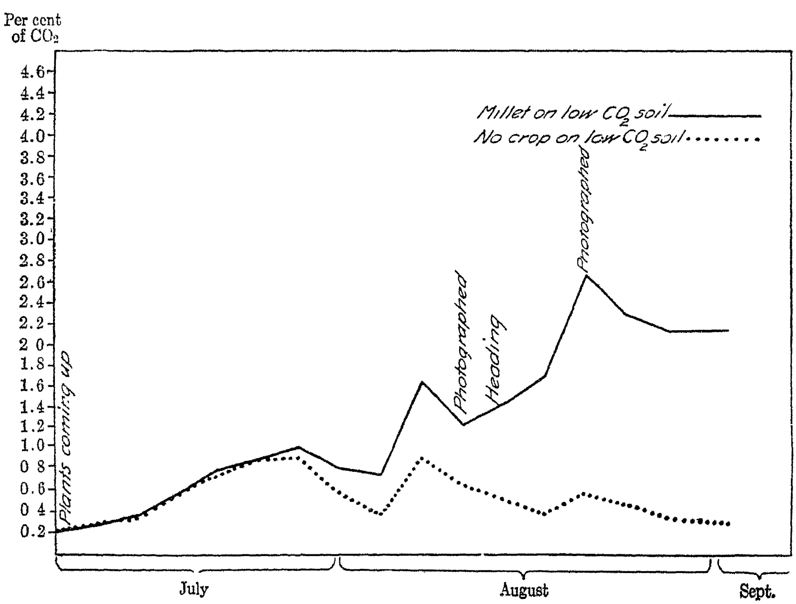

FIG. 57. CARBON DIOXIDE IN AIR FROM DUNKIRK CLAY LOAM NOT PREVIOUSLY CROPPED, CROPPED TO MILLET, AND FROM THE SAME SOIL LEFT BARE, 1918

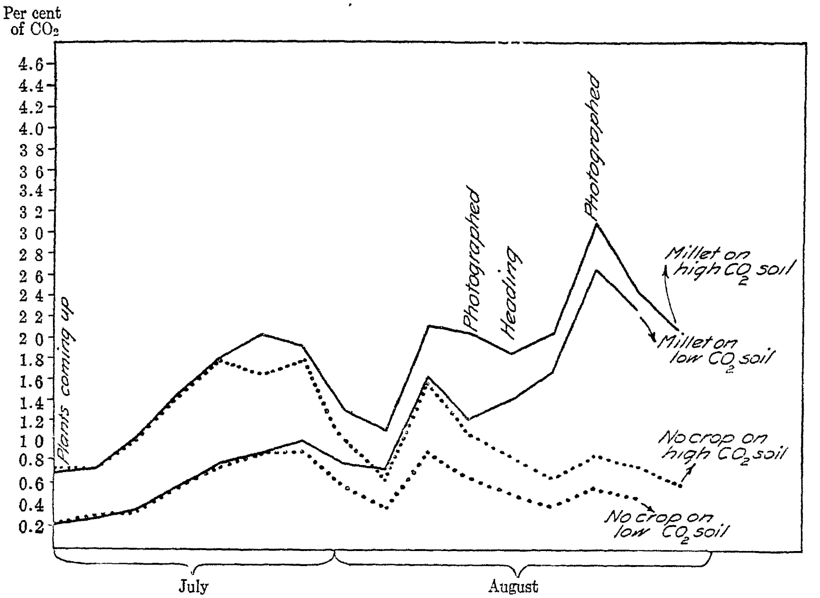

FIG. 58. RELATION BETWEEN THE AMOUNTS OF CARBON DIOXIDE IN AIR FROM CROPPED AND FROM UNCROPPED DUNKIRK CLAY LOAM HAVING HIGH AND LOW INITIAL CONTENTS OF CARBON DIOXIDE, RESPECTIVELY

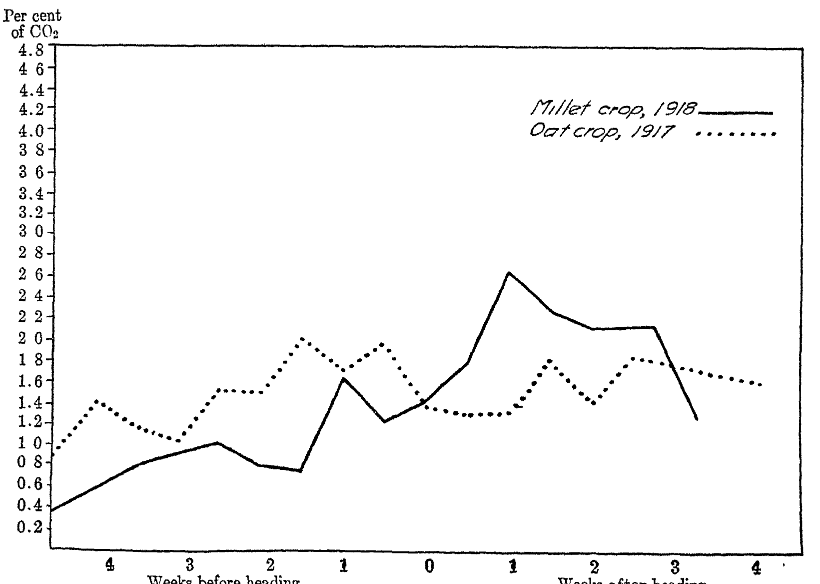

FIG. 59. RELATION BETWEEN THE AMOUNTS OF CARBON DIOXIDE IN AIR FROM DUNKIRK CLAY LOAM CROPPED TO OATS AND MILLET, RESPECTIVELY, BEFORE AND AFTER THE CROPS HEADED

growth of the millet would resemble in general that for the oat crops. The general tendency of the curve after August 25 was to fall as the plants advanced toward maturity, as in the case of the oat crops. It will be noticed from figure 59 that the actual amount of carbon dioxide produced on the soil cropped to millet was much the same as that produced on the oat soil. The maxima for the two oat crops of 1917 and 1918 were, respectively, 2.031 per cent and 3.343 per cent, while the corresponding figures for the millet crops in series 1 and 2 were 3.345 per cent and 2.715 per cent. It must be remembered, however, that there were but fifteen oat plants as compared with thirty millet plants; so that it may be concluded that an individual oat plant causes the production of about twice as much carbon dioxide as is produced by a millet plant.

Summary of experiment 2

From the results of the second experiment it may be concluded that a soil cropped to millet causes about the same fluctuations in carbon-dioxide production as are found in a soil growing an oat crop. In general, however, the oat crop gives the greatest production of carbon dioxide previous to heading, while the millet has its most marked effect a week or two after heading. It would seem also that an individual millet plant causes the production of approximately half as much carbon dioxide as an individual oat plant. From the close agreement between the two curves shown in figures 56, 57, and 58, for series 1 and 2, it may be assumed that in spite of slight differences in the previous treatment of the soil the excess carbon dioxide due to the crop was fairly similar where the crops growing showed no apparent differences in vigor. This is indicated also in figures 52 to 55, which show the two crops at an early and at a later stage of growth, the crop on the soil previously cropped twice to oats being designated as a high-carbon-dioxide crop and that on the soil that was previously bare being called a low-carbon-dioxide crop.

EXPERIMENT 3

As is pointed out in the review of literature, it is not clear whether or not the increased amount of carbon dioxide observed in a cropped soil is due to the excretion of carbon dioxide by plant roots (plant activity) or to the decay of root particles from the growing crop (bacterial activity). Data obtained in experiment 3 seem to throw a little light on this question. In this experiment, cans 1, 2, 3, and 4, which had previously grown two

crops of oats, had a considerably higher content of carbon dioxide, even after the removal of the crop and especially for about two months after harvest, than did cans 5, 6, 7, and 8, which remained uncropped for the two seasons.

After the oat crop from cans 1, 2, 3, and 4 was harvested, on July 1, 1918, cans 2 and 3, and the uncropped cans 6 and 8, were seeded to millet. Cans 1, 2, 3, and 4 are here designated as the high-carbon-dioxide series, while cans 5, 6, 7, and 8 are called the low-carbon-dioxide series. Thus, in the high-carbon-dioxide series, cans 1 and 4 were bare and cans 2 and 3 were cropped to millet; in the low-carbon-dioxide series, cans 5 and 7 were bare and cans 6 and 8 were cropped. All these cans were sampled in the usual way for carbon dioxide, and the data obtained are given in table 7 (appendix, page 360). The samples were taken twice a week at first, and later they were taken daily. The moisture in the soil was maintained at or near 30 per cent (oven-dry basis).

Within a month of seeding, the crop was thinned to thirty plants to a can; so that at the time when the effect of the plants on the carbon dioxide became noticeable (a month after seeding), the number of plants was the same for all cans.

Results

In table 7 it is shown that the differences between the percentages of carbon dioxide in the cropped soil and those in the uncropped soil in the high-carbon-dioxide series, were approximately the same as the corresponding differences in the low-carbon-dioxide series. In table 8 (appendix, page 361) it is seen that the majority of the differences in carbon-dioxide production by the crop in the two series (as determined by the difference between the amount of carbon dioxide produced by the cropped soil and that produced by the uncropped soil) was well within the limits of the experimental error. It seems, therefore, that the crops produced carbon dioxide quite independently, and that this production was not affected by the amount of carbon dioxide in the soil, at least not within the limits set by this experiment. How closely the difference between the curves for the cropped soils corresponded with those for the bare soils is shown in figure 58 (page 343).

The relationship between the temperature of the soil at the time of sampling, and the carbon dioxide in the bare soil and also that due to the crop on the low-carbon-dioxide series (determined by the difference as

explained above), is shown in table 9 (appendix, page 362) and in figure 60. It will be noticed that increases in temperature were more frequently accompanied by rises in carbon dioxide in the bare soil (indicating a relationship between bacterial activity and carbon-dioxide production), than by rises in the carbon dioxide produced by the crop. In the latter

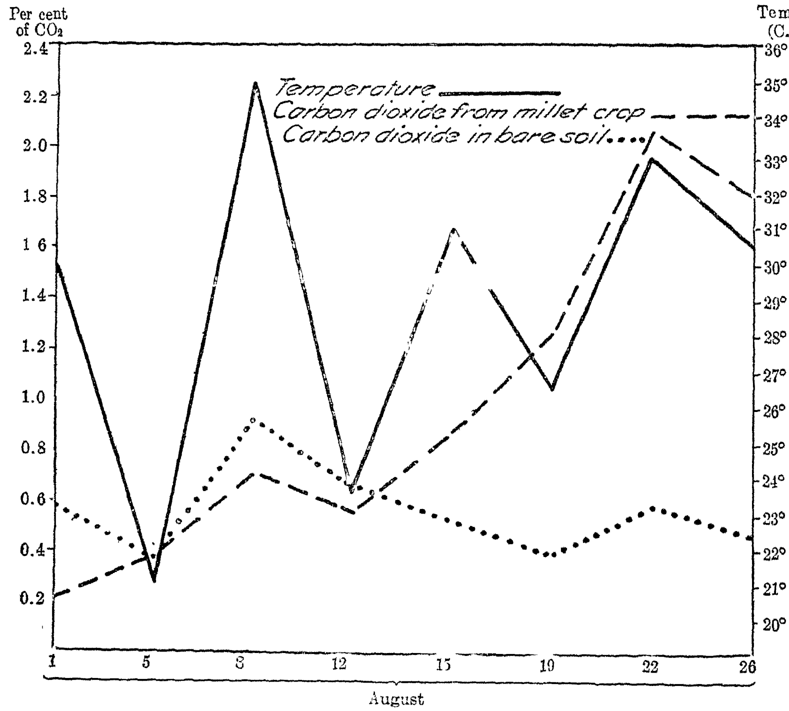

FIG. 60. RELATION BETWEEN THE CARBON DIOXIDE PRODUCED BY A MILLET CROP, THE CARBON DIOXIDE IN A BARE SOIL, AND THE TEMPERATURE OF THE SOIL AT THE TIME OF SAMPLING, 1918

case no such close relationship appeared, but the carbon dioxide increased gradually as the age of the plant advanced until the point of maximum carbon-dioxide production, after which there was a decline. This increase in carbon dioxide seems to have kept pace with the rate of growth of the plants. At the time when the plants ceased to grow actively (some time after heading), the carbon-dioxide production also fell off. If the excess

carbon dioxide in the cropped soil is due to the decomposition by bacteria of root particles thrown off from the growing crop, then one would expect to find that those factors which produce fluctuations in the carbon dioxide in the bare soil would produce corresponding, but more magnified, fluctuations in the cropped soil. But, as is pointed out above, a factor such as temperature did not produce corresponding changes in the two soils.

Again, if the decomposition of root particles from the growing crop gave rise to the increase of carbon dioxide in the cropped soil, it is reasonable to suppose that there would be a much larger increase in carbon dioxide at a time when the roots were beginning to die off rapidly, that is, toward the ripening period. Such, however, was not the case.

Summary of experiment 3

It is probable, therefore, that the larger part of the excess carbon dioxide produced in a cropped soil is due to respiratory activities of the plant roots, and that the amount resulting from the decay of root particles from the growing crop is small—altho after the crop has matured, any excess of carbon dioxide found is undoubtedly due to the decay of the mass of roots left in the soil. This excess, however, is very small when compared with the very large amounts of carbon dioxide found in the cropped soil at the time of heading, for example.

In support of the conclusion that the larger production of carbon dioxide in the cropped soil is due to respiratory activities of the plant roots, the data presented in experiment 1 show that there seems to be a correlation between the water requirements of the plant and the amount of carbon dioxide produced.

GENERAL SUMMARY

The results of the work reported in this paper with regard to the effect of crop and other factors on the production of carbon dioxide in a Dunkirk clay loam maintained at a constant moisture content of 30 per cent (oven-dry basis), may be summed up as follows:

1. An oat crop increased the production of carbon dioxide in the soil. This increase became marked after the first month from the time of seeding, and increased to a maximum just previous to or after the plants headed, after which there was a gradual decline.

2. Millet produced about the same increase in carbon dioxide as did oats, but the production of carbon dioxide by each millet plant was approximately half as much as the production by each oat plant. The most marked rise in the carbon-dioxide content of the soil occurred at a later period of growth in the case of the millet than in the case of the oats.

3. The cropped soil, after the crop was harvested, maintained a higher carbon-dioxide content than was found in the bare soil. This was due probably to the decomposition of plant roots left in the soil.

4. It would seem that increased plant activity (growth) is accompanied by increased carbon-dioxide production. This theory is supported by the fact that a relationship was shown between the carbon dioxide produced presumably by the crop, and the water transpired.

5. Fluctuations in the content of carbon dioxide in the bare soil were accompanied by similar fluctuations in the cropped soil only after the removal of the crop and before the crop had made much growth.

6. There appeared to be little relationship between the temperature of the soil at the time of sampling, and the carbon dioxide in the cropped soil or that assumed to be produced by the crop (determined by subtracting the carbon dioxide in the bare soil from that in the cropped soil).

7. In the bare soil the carbon dioxide was usually high during warm weather and low when the temperature decreased.

8. Very low atmospheric pressures were usually accompanied by an increase in the content of carbon dioxide in the bare soil.

9. The carbon dioxide produced presumably by the plant was about the same in soils having a high initial carbon-dioxide content as in those low in carbon dioxide, indicating the probability that plants and soil organisms act independently in producing carbon dioxide.

10. It is concluded from this work that the plant itself, and soil organisms, produce most of the carbon dioxide in the soil; that the plant often produces at the period of its most active growth many times as much carbon dioxide as is produced by soil organisms; and that the excess carbon dioxide in the soil growing a crop is due to respiratory activity of the plants rather than to the decay of root particles from the crop growing on the soil at the time of analysis.

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APPENDIX

TABLE 1. CARBON DIOXIDE (PER CENT BY VOLUME) IN CROPPED AND IN UNCROPPED SOIL (OATS, 1917)

Date of sampling	Temperature (centigrade)	Atmospheric pressure (inches)	Water added to maintain moisture content at 30 per cent (grams)	Carbon dioxide produced in		Difference (A—B)
				Cropped soil (A)	Uncropped soil (B)	
March 30	22.0°	29.06	. . . . . .	0.285±.009	0.281±.006	0.004±.011
April 12	23.0°	28.78	.	0.909±.017	0.777±.014	0.132±.022
April 15	23.0°	28.98	1.75	0.526±.007	0.498±.009	0.028±.011
April 19	30.0°	29.22	2.75	0.741±.019	0.736±.003	0.005±.019
April 22	21.0°	29.12	3.00	0.698±.017	0.653±.004	0.045±.017
April 26	22.0°	29.06	4.50	0.813±.013	0.714±.008	0.099±.015
April 30	23.0°	29.02	3.75	0.737±.014	0.653±.007	0.084±.016
May 4	17.0°	29.15	2.50	0.640±.013	0.559±.007	0.081±.015
May 7	21.5°	29.16	5.75	0.943±.027	0.776±.009	0.167±.028
May 11	22.0°	28.82	7.25	0.931±.037	0.632±.003	0.299±.037
May 14	30.0°	28.88	11.00	1.422±.048	0.878±.015	0.544±.050
May 18	16.0°	29.00	16.75	1.166±.047	0.475±.006	0.691±.047
May 21	21.0°	29.05	14.00	1.034±.037	0.452±.003	0.582±.037
May 25	16.0°	28.78	11.25	1.307±.040	0.415±.004	0.892±.040
May 28	17.0°	28.77	14.50	1.297±.034	0.477±.002	0.820±.034
June 1	20.0°	29.07	20.25	2.031±.102	0.648±.007	1.383±.102
June 4	29.0°	29.27	15.75	1.708±.060	0.698±.011	1.010±.060
June 8	21.0°	28.88	23.75	1.982±.101	0.530±.002	1.452±.101
June 11	22.0°	29.10	20.75	1.365±.042	0.452±.005	0.913±.043
June 15	13.0°	29.07	27.00	1.292±.024	0.416±.002	0.876±.024
June 18	22.0°	29.17	20.50	1.315±.025	0.419±.007	0.896±.026
June 22	20.5°	29.15	31.25	1.809±.030	0.480±.009	1.329±.032
June 25	30.0°	29.55	27.00	1.412±.033	0.466±.007	0.946±.034
June 29	20.0°	28.91	39.50	1.846±.028	0.496±.003	1.350±.028
July 2	28.0°	28.92	24.00	1.778±.032	0.620±.008	1.158±.033
July 6	16.0°	29.16	. . . . . .	0.799	0.393±.002	. . . .
July 9	24.0°	28.95	25.00	1.614±.014	0.449±.008	1.165±.016
July 13	19.0°	28.92	20.00	1.699±.018	0.394±.001	1.305±.018
July 16	30.0°	29.14	16.00	1.781±.052	0.633±.007	1.148±.052
July 20	20.0°	29.24	7.50	1.111±.016	0.491±.005	0.620±.017
July 23	35.0°	29.05	8.00	1.595±.030	0.954±.015	0.641±.033
July 27	23.0°	28.99	6.00	1.261±.044	0.686±.007	0.575±.044
July 30	35.0°	28.93	3.50	1.475±.029	0.959±.007	0.516±.030
August 3	21.0°	29.07	6.00	1.040±.032	0.643±.007	0.397±.032
August 6	25.0°	29.22	3.50	1.028±.028	0.629±.007	0.399±.029
August 10	19.5°	29.05	1.50	0.706±.012	0.425±.003	0.281±.012
August 13	26.0°	29.21	2.75	0.876±.012	0.581±.005	0.295±.013
August 17	20.5°	29.00	1.25	0.781±.019	0.478±.003	0.303±.019
August 20	32.0°	28.97	. . .	0.909±.012	0.704±.002	0.205±.012
August 24	22.0°	28.71	. . . .	0.765±.013	0.526±.007	0.239±.015

TABLE 1 (*concluded*)

Date of sampling	Temperature (centigrade)	Atmospheric pressure (inches)	Water added to maintain moisture content at 30 per cent (grams)	Carbon dioxide produced in		Difference (A−B)
				Cropped soil (A)	Uncropped soil (B)	
August 27	29.5°	29.20	.	0.729±.009	0.538±.005	0.191±.010
August 31	14.0°	29.37	.	0.345±.007	0.244±.001	0.101±.008
Sept. 3	25.0°	29.24		0.659±.015	0.488±.001	0.171±.015
Sept. 7	14.0°	29.23	. .	0.376±.007	0.256±.003	0.120±.008
Sept. 10	14.5°	29.34	.	0.289±.004	0.195±.003	0.094±.005
Sept. 14	15.5°	29.41	. .	0.385±.010	0.255±.007	0.130±.013
Sept. 17	25.0°	29.31	.. ... .	0.544±.008	0.378±.004	0.166±.009
Sept. 21	18.0°	29.06	. .	0.554±.010	0.348±.005	0.206±.011
Sept. 24	24.0°	29.40	.. . ...	0.415±.003	0.266±.003	0.149±.004
Sept. 28	18.0°	28.93	. ..	0.495±.012	0.328±.003	0.167±.013
Oct. 5	16.0°	28.89	.... .	0.309±.010	0.211±.004	0.098±.011
Oct. 19	24.0°	28.92	.... .	0.404±.010	0.288±.006	0.116±.011
Nov. 2	17.0°	29.40	.. ...	0.382±.008	0.259±.004	0.123±.009
Nov. 16	19.0°	29.08	....	0.424±.013	0.301±.016	0.123±.021
Nov. 30	17.0°	29.15	. ...	0.280±.008	0.192±.005	0.088±.010
Dec. 14	17.5°	28.69	....	0.356±.020	0.216±.007	0.140±.021

TABLE 2. CARBON DIOXIDE (PER CENT BY VOLUME) IN CROPPED AND IN UNCROPPED SOIL (OATS, 1918)

Date of sampling	Temperature (centigrade)	Atmospheric pressure (inches)	Water added to maintain moisture content at 30 per cent (grams)	Carbon dioxide produced in		Difference (A—B)
				Cropped soil (A)	Uncropped soil (B)	
Jan. 3	18 0°	29.24	....	0.373±.020	0.229±.005	0.144±.021
Jan. 16	18 5°	28 84	....	0.346± 014	0 162±.002	0 184±.014
Jan. 31	18 0°	29 32	....	0 315± 009	0 223±.006	0 092± 011
Feb. 7	20.0°	29.20	....	0.318± 010	0.226±.002	0 092± 010
Feb. 11	20 0°	28 98	....	0 340± 010	0.249±.009	0 091±.013
Feb. 14	22 5°	28 97	....	0 401± 010	0.255±.009	0.146± 013
Feb. 18	18 0°	29 68	....	0 370± 010	0.221± 006	0.149±.012
Feb. 21	20 0°	28 75	5 00	0 509± 014	0.258± 008	0.251±.016
Feb. 25	20 5°	28 83	3.75	0 445± 009	0.195±.006	0.250± 011
Feb. 28	20 0°	29.25	5.00	0 595± 010	0.240± 008	0.355± 012
March 4	16.0°	29 34	5.75	0 695±.016	0.236±.008	0.459± 018
March 7	20.0°	28.96	3.25	0 639± 017	0.295±.007	0.344± 018
March 11	16.0°	29.54	9.75	0 834±.010	0.236±.006	0.598± 020
March 14	20 0°	28.48	9.75	0.969±.029	0.226±.006	0.743±.029
March 18	18 0°	29 15	14.25	1.688±.027	0.285±.006	1.403±.028
March 21	25 0°	28 88	19.75	2.290±.060	0.471±.012	1.819±.062
March 25	18 0°	28 84	24 00	2.103± 030	0.259±.009	1.844±.031
March 28	21 0°	29 39	17.50	2.224± 055	0.319±.010	1.905± 056
April 1	21 0°	28.81	30.75	2.514±.039	0 331±.010	2.183±.041
April 4	20 0°	29.08	27.00	2.314±.033	0.318±.006	1.996± 034
April 8	19 0°	29.39	33.25	1.865±.025	0.170±.009	1.695±.026
April 11	20 5°	29.26	14.00	3.129±.033	0.188±.004	2 941±.034
April 15	20.5°	29.22	22 25	2 704±.072	0.320±.006	2.384±.072
April 18	24 0°	28 83	29 75	2 580±.035	0.311±.004	2.269±.085
April 22	21.0°	28 68	24 25	2.129±.089	0 211±.005	1 918±.089
April 25	23.5°	29 28	15.00	2.678± 056	0.303±.006	2.375±.057
April 29	22 5°	28 97	38.50	2.418± 040	0.236±.005	2.182±.041
May 2	23 5°	29.20	21 00	2 039± 046	0.211±.003	1.858±.046
May 6	23 0°	29 07	31.00	3 343± 029	0.389± 003	2.954±.029
May 9	27 0°	28 93	30 25	2 741± 041	0.345±.004	2.396± 041
May 13	23 0°	28 92	24.25	2.643±.045	0.296±.004	2.347± 045
May 16	27 5°	29 41	21.00	2.753±.071	0.266± 004	2.487±.071
May 20	22 0°	29 12	23 00	2.600±.081	0 276±.004	2.324± 081
May 23	24 0°	29 30	17.75	2.934±.044	0.295± 006	2.639± 044
May 27	21 5°	29 05	17.25	2.153±.065	0.259± 006	1.894± 065
May 30	23 5°	29 17	16.75	1.518±.018	0 234± 005	1.254±.018
June 3	20.5°	29.19	27.00	2.045±.011	0 344±.005	1.701±.012
June 6	22.5°	29 10	18.25	1.361± 015	0 299± 005	1.062± 015
June 10	17 5°	29.11	17 75	1.120± 017	0.199± 003	0.921± 017
June 13	21 5°	28 77	10.75	1 070±.017	0 220± 004	0.850±.018
June 17	19 5°	29 09	15.50	1.170± 007	0 271± 005	0 899± 009
June 20	24 0°	29 21	11 75	1 004±.009	0 249± 002	0 755±.009
June 24	14 0°	29.00	5.50	0.519±.007	0.140±.002	0.379±.007

TABLE 2 (*concluded*)

Date of sampling	Temperature (centigrade)	Atmospheric pressure (inches)	Water added to maintain moisture content at 30 per cent (grams)	Carbon dioxide produced in		Difference (A−B)
				Cropped soil (A)	Uncropped soil (B)	
June 27	28.0°	29.06	6.00	1.169±.019	0.396±.003	0.773±.019
July 1	20.5°	28.84	5.25	1.500±.041	0.369±.006	1.131±.041
July 4	28.5°	29.33	....	1.023±.014	0.336±.005	0.690±.015
July 8	17.0°	28.99	....	0.763±.040	0.215±.002	0.548±.040
July 11	21.5°	29.12	....	0.745±.024	0.295±.007	0.450±.025
July 15	19.0°	29.12	....	1.028±.018	0.333±.004	0.695±.019
July 18	30.0°	28.94	....	1.430±.040	0.578±.011	0.852±.042
July 22	23.0°	29.31	....	1.778±.004	0.750±.021	1.028±.021
July 25	30.0°	29.22	....	1.648±.035	0.895±.017	0.753±.039
July 29	24.0°	29.14	....	1.788±.001	0.920±.021	0.868±.021
August 1	30.0°	29.07	....	1.020±.038	0.580±.029	0.440±.048
August 5	21.0°	28.92	....	0.653±.006	0.375±.017	0.278±.018
August 8	35.0°	29.03	....	1.563±.013	0.920±.036	0.643±.038
August 12	23.5°	29.16	....	1.058±.028	0.635±.012	0.423±.030
August 14	28.0°	29.07	....	1.315±.007	0.790±.026	0.525±.027
August 15	31.0°	29.21	....	0.885±.024	0.525±.021	0.360±.032
August 16	32.0°	29.16	....	0.835±.016	0.505±.021	0.330±.026
August 17	29.5°	29.50	....	0.760±.021	0.478±.023	0.282±.031
August 19	26.5°	29.53	....	0.668±.006	0.400±.014	0.268±.015
August 21	33.0°	29.21	....	0.715±.026	0.430±.010	0.285±.028
August 22	33.0°	29.17	....	0.888±.013	0.588±.018	0.300±.022
August 23	33.0°	29.10	....	0.988±.004	0.633±.014	0.355±.015
August 24	34.0°	29.02	....	1.145±.005	0.695±.007	0.450±.009
August 26	30.5°	28.96	....	0.788±.016	0.468±.006	0.320±.018
August 27	30.0°	29.28	....	0.688±.006	0.448±.020	0.240±.021

TABLE 3. RELATION BETWEEN THE CARBON DIOXIDE IN THE CROPPED SOIL DURING THE PERIOD OF MOST ACTIVE PLANT GROWTH, AND THE WATER TRANSPIRED EACH WEEK (OATS, 1917)

Date	Water transpired (grams)	Total water transpired each week (grams) (A)	Cropped soil		Uncropped soil		Difference in carbon dioxide C—E (F)	Per cent of carbon dioxide to each pound of water	
			Carbon dioxide (per cent) (B)	Average carbon dioxide for the week (per cent) (C)	Carbon dioxide (per cent) (D)	Average carbon dioxide for the week (per cent) (E)		$\frac{F}{A}$ (G)	$\frac{C}{A}$ (H)
May 7 May 11	5.75 7.25	13.00	0.943 0.931	0.937	0.776 0.632	0.704	0.233	0.018	0.072
May 14 May 18	11.00 16.75	27.75	1.422 1.166	1.294	0.878 0.475	0.677	0.617	0.022	0.047
May 21 May 25	14.00 11.25	25.25	1.034 1.314	1.174	0.452 0.415	0.434	0.740	0.029	0.046
May 28 June 1	14.50 20.25	34.75	1.297 2.031	1.664	0.477 0.648	0.563	1.101	0.032	0.048
June 4 June 8	15.75 23.75	39.50	1.708 1.982	1.845	0.698 0.530	0.614	1.231	0.031	0.017
June 11 June 15	20.75 27.00	47.75	1.365 1.292	1.329	0.452 0.416	0.434	0.895	0.019	0.028
June 18 June 22	20.50 31.25	51.75	1.315 1.809	1.562	0.419 0.480	0.450	1.112	0.021	0.030
June 25 June 29	27.00 39.50	66.50	1.412 1.816	1.629	0.166 0.496	0.481	1.148	0.017	0.024
July 2 July 6	24.00 .		1.778 . . .		0.620 0.393	0.507	. . . . .	. . . . . .	. . . .
July 9 July 13	25.00 20.00	45.00	1.611 1.699	1.657	0.419 0.391	0.422	1.235	0.027	0.037
				Mean				0.024 ± .0012	0.012 ± .0031
				Standard deviation				0.0054 ± .0009	0.0136 ± .0022
				Coefficient of variability				22.5 ± 3.74	37.10 ± 5.65

TABLE 4. RELATION BETWEEN THE CARBON DIOXIDE IN THE CROPPED SOIL DURING THE PERIOD OF MOST ACTIVE PLANT GROWTH, AND THE WATER TRANSPIRED EACH WEEK (OATS, 1918)

Date	Water transpired (grams)	Total water transpired each week (grams) (A)	Cropped soil: Carbon dioxide (per cent) (B)	Cropped soil: Average carbon dioxide for the week (per cent) (C)	Uncropped soil: Carbon dioxide (per cent) (D)	Uncropped soil: Average carbon dioxide for the week (per cent) (E)	Difference in carbon dioxide C−E (F)	Per cent of carbon dioxide to each pound of water: $\frac{F}{A}$ (G)	Per cent of carbon dioxide to each pound of water: $\frac{C}{A}$ (H)
March 4 March 7	5.75 3.25	9 00	0.695 0.639	0.667	0 236 0.295	0.266	0.401	0 045	0 074
March 11 March 14	9.75 9.75	19.50	0.834 0.969	0.902	0 236 0 226	0 231	0.671	0 034	0.046
March 18 March 21	14.25 19 75	34 00	1.688 2.290	1 989	0.285 0 471	0 378	1.611	0.047	0.059
March 25 March 28	24 00 17.50	41 50	2.103 2 224	2.161	0.259 0.319	0 289	1.875	0 045	0.052
April 1 April 4	30.75 27.00	57 75	2 514 2.314	2.414	0.331 0.318	0.325	2.089	0.036	0 042
April 8 April 11	33.25 14.00	47 25	1.865 3.129	2.497	0 170 0 188	0.179	2 318	0.049	0.053
April 15 April 18	22 25 29.75	52 00	2.704 2.580	2.642	0.320 0.311	0.316	2.326	0.045	0.051
April 22 April 25	24.25 15 00	39 25	2.129 2 678	2.404	0.211 0.303	0.257	2.147	0.055	0.061
April 29 May 2	38.50 21 00	59.50	2.418 2.069	2.244	0.236 0.211	0.224	2 020	0.034	0.038
May 6 May 9	31.00 30.25	61.25	3 343 2.741	3 042	0 389 0.345	0 367	2 675	0.044	0 050
Mean								0.043 ± 0014	0 053 ± 0022
Standard deviation								0.0065 ±.0010	0 0102 ± 0015
Coefficient of variability								15 1 ±2 32	19 17 ±3 12

TABLE 5. RELATION BETWEEN THE DRY WEIGHT OF THE CROP AND THE CARBON DIOXIDE GIVEN OFF BY PLANT ROOTS

(From Stoklasa and Ernest, 1909)

Crop	Total dry matter produced in 84 days (milligrams)	Total carbon dioxide produced in 84 days (milligrams)	Milligrams of carbon dioxide produced to each milligram of dry matter
Barley	34,493	1,267	0 037
Rye	27,046	1,053	0 039
Oats	26,215	793	0 030
Wheat	18,375	784	0.043
Average	26,532	974	0.037

TABLE 6. CARBON DIOXIDE (PER CENT BY VOLUME) IN CROPPED AND IN UNCROPPED SOIL (MILLET, 1918)

Date of sampling	Carbon dioxide produced in			
	Series 1 (high CO_2 soil)		Series 2 (low CO_2 soil)	
	Cropped (per cent)	Bare (per cent)	Cropped (per cent)	Bare (per cent)
July 8	0.713± 016	0 763±.040	0.210±.002	0 215±.002
July 11	0.763± 006	0 745±.024	0.283±.001	0.295±.007
July 15	1 045± 031	1.028±.018	0.358± 001	0 333±.004
July 18	1.455± 050	1 430± 040	0.578±.001	0.578±.001
July 22	1 803± 032	1 778±.004	0 795±.014	0 750±.021
July 25	2.015± 079	1.648± 035	0 908±.059	0.895± 017
July 29	1 922± 101	1 788±.001	1.008± 054	0 920±.021
August 1	1 305± 055	1.020±.038	0.798±.039	0.580±.029
August 5	1 133± 006	0.653±.006	0 750± 052	0.375±.017
August 8	2 115± 017	1.563± 013	1 628±.161	0.920±.036
August 12	2 025±.021	1 088±.028	1 223±.018	0 665±.012
August 14	2 448± 023	1.315±.007	1 710±.043	0 790±.026
August 15	1.864± 016	0.885±.024	1 405± 012	0 525±.021
August 16	1 950± 010	0.835± 016	1.480±.033	0.505±.021
August 17	2 108± 018	0 760± 021	1 683±.049	0 478±.023
August 19	2 040± 048	0 668± 006	1 683± 042	0 400±.014
August 21	2 288± 016	0 715± 026	1 948±.016	0 430±.010
August 22	3 098± 023	0.888±.013	2 655±.055	0.588±.018
August 23	3 095±.0[illegible]0	0.988±.004	2.715±.074	0.633± 014
August 24	3 345± 035	1.145±.005	2.690±.060	0.695±.007
August 26	2.465±.005	0.788± 016	2.275±.064	0.468± 006
August 27	2.198±.009	0.688±.006	2.133±.075	0.448± 020
August 28	2.245±.031	0 690±.036	1 958±.056	0.348±.004
August 29	2 093±.039	0.613± 004	2 120±.088	0.358±.006
August 31	1.983± 011	0 590± 007	2 245±.114	0.370±.010
September 3	1 770±.021	0 533± 011	2.143±.068	0.310±.005

TABLE 7. CARBON DIOXIDE (PER CENT BY VOLUME) IN CROPPED AND IN UNCROPPED SOILS HAVING DIFFERENT INITIAL CARBON-DIOXIDE CONTENTS (MILLET, 1918)

Date of sampling	Carbon dioxide produced in				Difference in carbon dioxide produced by various soils				
	High CO_2 soil		Low CO_2 soil		I (A—C)	II (B—D)	III (A—B)	IV (C—D)	V (III—IV)
	Cropped (A)	Bare (B)	Cropped (C)	Bare (D)					
July 8	0.713±.016	0.763±.010	0.210±.002	0.215±.002	+0.503±.016	+0.548±.010	−0.050±.013	−0.005±.003	−0.015±.013
July 11	0.763±.006	0.715±.024	0.283±.001	0.295±.007	+0.480±.006	+0.450±.025	+0.018±.025	−0.012±.007	+0.030±.026
July 15	1.045±.031	1.028±.018	0.358±.001	0.333±.004	+0.687±.031	+0.695±.019	+0.017±.036	+0.025±.004	−0.008±.036
July 18	1.155±.050	1.130±.010	0.578±.001	0.578±.001	+0.577±.051	+0.552±.012	+0.025±.051	0.000±.016	+0.025±.066
July 22	1.803±.032	1.778±.004	0.795±.014	0.750±.021	+1.008±.035	+1.028±.021	+0.025±.032	+0.045±.025	−0.020±.011
July 25	2.015±.079	1.618±.035	0.908±.059	0.895±.017	+1.107±.099	+0.753±.039	+0.367±.086	+0.013±.061	+0.351±.106
July 29	1.923±.101	1.788±.001	1.008±.074	0.920±.021	+0.915±.114	+0.868±.021	+0.135±.101	+0.088±.058	+0.017±.116
August 1	1.305±.055	1.020±.038	0.798±.039	0.580±.029	+0.507±.067	+0.440±.048	+0.285±.067	+0.218±.049	+0.067±.082
August 5	1.133±.006	0.653±.006	0.750±.052	0.375±.017	+0.383±.052	+0.278±.018	+0.480±.008	+0.375±.055	+0.105±.055
August 8	2.115±.017	1.563±.013	1.628±.161	0.920±.036	+0.487±.162	+0.643±.038	+0.552±.021	+0.708±.170	−0.156±.167
August 12	2.025±.021	1.088±.028	1.223±.018	0.665±.012	+0.802±.028	+0.423±.030	+0.937±.035	+0.558±.022	+0.379±.041
August 14	2.448±.028	1.315±.007	1.710±.043	0.790±.026	+0.738±.051	+0.525±.027	+1.133±.029	+0.920±.050	+0.213±.058
August 15	1.864±.016	0.885±.024	1.105±.012	0.525±.024	+0.759±.035	+0.360±.032	+0.979±.041	+0.880±.024	+0.103±.048
August 16	1.950±.010	0.835±.016	1.480±.033	0.505±.021	+0.470±.034	+0.330±.026	+1.115±.019	+0.975±.039	+0.140±.017
August 17	2.103±.018	0.760±.021	1.683±.049	0.178±.023	+0.425±.052	+0.582±.031	+1.348±.028	+1.505±.054	+0.143±.061
August 19	2.040±.018	0.668±.006	1.683±.012	0.400±.014	+0.357±.065	+0.268±.015	+1.372±.018	+1.283±.014	+0.089±.066
August 21	2.288±.016	0.715±.026	1.948±.016	0.430±.010	+0.340±.023	+0.285±.028	+1.573±.031	+1.518±.019	+0.055±.036
August 22	3.098±.023	0.888±.013	2.655±.055	0.588±.018	+0.443±.060	+0.300±.022	+2.210±.026	+2.067±.058	+0.143±.064
August 23	3.095±.060	0.988±.004	2.715±.074	0.633±.014	+0.380±.095	+0.355±.015	+2.107±.062	+2.082±.075	+0.025±.096
August 24	3.315±.035	1.115±.005	2.690±.060	0.695±.007	+0.625±.062	+0.420±.009	+2.200±.018	+1.995±.060	+0.205±.063
August 26	2.465±.005	0.788±.016	2.275±.064	0.468±.006	+0.190±.064	+0.320±.018	+1.677±.018	+1.807±.064	−0.130±.067
August 27	2.198±.009	0.688±.006	2.133±.075	0.448±.020	+0.065±.075	+0.240±.021	+1.510±.011	+1.685±.077	−0.175±.078
August 28	2.245±.031	0.690±.036	1.958±.055	0.348±.004	+0.287±.064	+0.342±.036	+1.555±.048	+1.610±.056	−0.055±.074

TABLE 8. CARBON DIOXIDE (PER CENT BY VOLUME) PRODUCED APPARENTLY BY THE MILLET CROP, 1918 DETERMINED BY SUBTRACTING THE AMOUNT OF CARBON DIOXIDE IN THE BARE SOIL FROM THAT IN THE CROPPED SOIL

Date of sampling	Carbon dioxide apparently produced by millet crop in		Difference (I—II)
	High CO_2 soil (I)	Low CO_2 soil (II)	
July 8.	—0 050± 043	—0 005± 003	—0 045± 043
July 11.	+0 018±.025	—0 012± 007	+0 030± 026
July 15	+0 017±.036	+0 025± 004	—0 008± 036
July 18.	+0 025± 064	0 000± 016	+0 025±.066
July 22	+0 025± 032	+0 045± 025	—0 020± 041
July 25	+0 367± 086	+0 013±.061	+0 354±.106
July 29	+0 135± 101	+0 088±.058	+0 047±.116
August 1.	+0 285± 067	+0 218±.049	+0 067± 082
August 5.	+0 480± 008	+0.375±.055	+0 105± 055
August 8.	+0 552± 021	+0 708±.170	—0 156± 167
August 12.	+0 937± 035	+0 558± 022	+0 379± 041
August 14.	+1 133± 029	+0 920±.050	+0.213±.058
August 15.	+0 979± 041	+0 880± 024	+0 103±.048
August 16.	+1 115± 019	+0.975± 039	+0.140± 047
August 17.	+1 348± 028	+1.205± 054	+0 143± 061
August 19.	+1.372± 048	+1 283± 044	+0 089± 066
August 21.	+1.573± 031	+1.518± 019	+0 055± 036
August 22	+2 210± 026	+2 067± 058	+0 143± 064
August 23	+2 107± 062	+2 082±.075	+0 025± 096
August 24.	+2 200± 018	+1.995± 060	+0.205± 063
August 26	+1 677± 018	+1 807± 064	—0 130± 067
August 27.	+1 510± 011	+1 685±.077	—0 175± 078
August 28.	+1.555± 048	+1 610±.056	—0 055±.074

TABLE 9. CARBON DIOXIDE (PER CENT BY VOLUME) IN CROPPED AND IN UNCROPPED SOIL OF LOW INITIAL CARBON-DIOXIDE CONTENT (MILLET, 1918)

Date of sampling	Temperature (centigrade)	Atmospheric pressure (inches)	Carbon dioxide produced in		Difference (I—II)
			Cropped soil (I)	Uncropped soil (II)	
July 8	17.0°	28.99	0.210±.002	0.215±.002	—0.005±.003
July 11	21.5°	29.12	0.283±.001	0.295±.007	—0.012±.007
July 15	19.0°	29.12	0.358±.001	0.333±.004	+0.025±.004
July 18	30.0°	28.94	0.578±.001	0.578±.001	0.000±.016
July 22	23.0°	29.31	0.795±.014	0.750±.021	+0.045±.025
July 25	30.0°	29.22	0.908±.059	0.895±.017	+0.013±.061
July 29	24.0°	29.14	1.008±.054	0.920±.021	+0.088±.058
August 1	30.0°	29.07	0.798±.039	0.580±.029	+0.218±.049
August 5	21.0°	28.92	0.750±.052	0.375±.017	+0.375±.055
August 8	35.0°	29.03	1.628±.161	0.920±.036	+0.708±.170
August 12	23.5°	29.16	1.223±.018	0.665±.012	+0.558±.022
August 14	28.0°	29.07	1.710±.043	0.790±.026	+0.920±.050
August 15	31.0°	29.21	1.405±.012	0.525±.021	+0.880±.024
August 16	32.0°	29.16	1.480±.033	0.505±.021	+0.975±.039
August 17	29.5°	29.50	1.683±.049	0.478±.023	+1.205±.054
August 19	26.5°	29.53	1.683±.042	0.400±.014	+1.283±.004
August 21	33.0°	29.21	1.948±.016	0.430±.010	+1.518±.019
August 22	33.0°	29.17	2.655±.055	0.588±.018	+2.067±.058
August 23	33.0°	29.10	2.715±.074	0.633±.014	+2.082±.075
August 24	34.0°	29.02	2.690±.060	0.695±.007	+1.995±.060
August 26	30.5°	28.96	2.275±.064	0.468±.006	+1.807±.064

Memoir 29 *The Lecithin Content of Butter and Its Possible Relationship to the Fishy Flavor*, the third pre-[illegible] in this series of publications, was mailed on December 23, 1919.

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PHOSPHORUS IN BUTTER

J. T. CUSICK

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CONTENTS

PHOSPHORUS IN BUTTER

PHOSPHORUS IN BUTTER[1]

J. T. Cusick

For a long time manufacturers of butter, and students of its manufacture, have been searching for a method that would give a product capable of withstanding storage conditions and preserving its original quality. The bulk of the methods investigated have dealt with the way in which the raw material is treated and handled before churning. While this earlier treatment does influence the keeping qualities of the churned product, the chemical changes produced, as evidenced in "off flavors," have been investigated in only a few instances. Bacterial, chemical, and enzymic action on butter during its period of storage have been studied almost entirely from the manufacturer's viewpoint, but the results of the methods used by the manufacturer have led to no definite conclusions as to the chemical changes produced by the various manufacturing processes. It is, therefore, with the view of adding some information to present knowledge of the chemical changes occurring in butter during storage, that the rôle played by phosphorus is discussed here. It is clearly shown that the various methods of handling the raw material, and the ways in which it is treated by the manufacturer before churning, have a pronounced influence on the phosphorus in its various forms. One cannot properly interpret "off flavors" and the like without knowing, first, what constituents undergo change, and secondly, what products of decomposition are formed and by what agents.

REVIEW OF LITERATURE

Friis (1897)[2] states that pasteurization of milk or cream appreciably decreases the content of free fatty acids in the resulting butter. His experiments show that

> the amount of free acids in the butter is greatly decreased when the milk or the cream is heated previous to the churning; pasteurization of the milk reduces the free fatty acid content of the fat more than pasteurization of the cream. About half the acidity of fresh sour-cream butter is due to free fatty acids in the butter, and the other half to the acidity of the buttermilk remaining in the butter.

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[1] Also presented to the Faculty of the Graduate School of Cornell University, December, 1919, as a major thesis in partial fulfillment of the [illegible] for the degree of doctor of philosophy.
The wor[illegible] lone in th[illegible] of Agricultural Chemistry of the New York State College of [illegible] University, under the direction of Professor George W. Cavanaugh.

[2] Dates in parenthesis refer to *Literature Cited*, page 186.

Schmidt (1898) found that pasteurization of the cream at high temperatures, and salting of the butter, lowered the acidity and the number of bacteria in the butter. Salted butter did not become rancid as soon as did unsalted butter, in his experiments.

Fishy flavor in butter is due to a bacterium, according to O'Callaghan (1902), and is remedied by pasteurization. This theory of the cause of fishy flavor is denied by many investigators, who claim that the flavor is due to enzymic or chemical decomposition.

Steiner (1901) states that pasteurization gives as high a loss of albumin in the butter as 82.5 per cent. The amount of loss depends on the temperature at which the milk is heated and on the time of heating.

Harcourt (1903) found that the amount of nitrogenous matter in butter does not affect its keeping quality.

A primarily practical viewpoint of the question was taken by Lee (1909), who conducted pasteurizing experiments on "farm-skimmed" cream. He concluded that pasteurizing does not affect the body, or texture, of butter, and does not improve the quality of butter made from sour "farm-skimmed" cream.

According to Sayer, Rahn, and Farrand (1908), the use of starter in preparing cream for churning has a decided influence on the butter. Pure cultures of starter gave butter of a high score, according to these investigators. Lindsey (1908) placed great emphasis on care in the quality of the starter to be used, and found that the flavor of butter depends primarily on the cleanliness of the milk, the stage of lactation of the animal, the skill and care of the butter maker, and, especially, the character of the starter employed. He concluded also that normal foodstuffs must be considered of secondary importance in establishing butter flavor.

McKay and Bower (1908) studied the moisture content of butter as it affects the quality of the product. Their efforts led them to conclude that high water content between 15 and 16 per cent does not necessarily mean a low score, nor does less than 13 per cent mean a high score.

Rogers and Gray (1909) made butter from pasteurized and from unpasteurized cream of varying degrees of acidity, and stored it at temperatures of 32°, 10°, and −10° F. They state:

> The butter made from unripened unpasteurized cream always developed a cheesy or rancid flavor. The butter made from ripened cream, both pasteurized and unpasteurized, developed cold-storage, fishy, and other flavors typical of storage butter. In all cases the overripe butter showed marked deterioration. The butter made from pasteurized cream

without starter usually retained its flavor with little or no change. Even at 32° F. the sweet-cream butter deteriorated very little . .

Butter made from pasteurized cream with starter added, ... retained its fresh flavor better than the ripened-cream butter, but was not quite equal in keeping quality to that made from sweet pasteurized cream.

High acidity reduces the keeping quality, according to these workers.

Melick (1909:281) found that "the use of commercial lactic acid as a substitute for starter proved advantageous only when used in very rancid cream....."

Saponification of the butterfat takes place during storage, according to Vincent (1910), increasing the insoluble fatty acids. The soluble and the insoluble fatty acids are formed directly by decomposition and by synthesis, respectively. It is evident that the glycerides of the insoluble acids are changed to a greater degree than are those of the soluble acids. Vincent found also that glycerol is present in old butter and in old cream, but not in milk.

During experiments in the manufacture of butter and cheese, Dean (1910) found that when 10 per cent of starter was added to cream for making butter, there was a greater loss of fat in the pasteurized than in the raw cream. This loss increased with the increase of acidity in the cream at the time of pasteurization. There was little difference in the quality of fresh butter when pasteurized at different temperatures, but the keeping quality was improved by pasteurizing the cream at a temperature between 60° and 82° F.

Larsen, Lund, and Miller (1910) found that the acidity of thoroughly washed butter at the time of making was less than that of butter that was washed but little, by the equivalent of 0.3 cubic centimeter of N/10 alkali to 10 grams of butter. At the end of sixteen weeks this difference had increased to only 0.5 cubic centimeter. Butter made from pasteurized cream did not increase in acidity as rapidly as did butter made from raw cream. The average difference between the two samples immediately after churning was only 0.1 cubic centimeter, but after the butter had been kept in storage for sixteen weeks this difference had increased to 1.1 cubic centimeters. During the sixteen weeks the acidity of the pasteurized-cream butter had increased only 0.6 cubic centimeter, as compared with an increased acidity of 1.6 cubic centimeters in the raw-cream butter. The acidity in lightly salted butter increased by 4.7 cubic centimeters in sixteen weeks, as compared with an increase of 1.6 cubic centimeters

for heavily salted butter. The acidity of ripened-cream butter increased more than did the acidity of sweet-cream butter. The bulletin states (page 715):

> These results indicate that butter from fresh and properly ripened cream not over one day old keeps better than does butter made from sweet cream. The butter fat from very fresh cream is apparently in a more stable condition than is the fat in the sour cream over one day old, and not so predisposed to decomposition. It indicates that butterfat, in the form of butter, keeps better than does [illegible] form of cream, even though it be in properly ripened cream.

It has been found by Rahn, Brown, and Smith (1909) that there is very little loss of lactose during the storage of butter, and apparently little or no relation between the water-soluble acids and the amount of lactose lost. The butter having the highest initial scores showed the least change in its amino nitrogen content. Butter scoring a little lower and made from cream of a poor quality showed an increased decomposition of protein. The butter with the lowest score yielded the largest amount of protein cleavage products.

The influence of the alkalinity of the wash water was investigated by Meijeringh (1911). He found that the water content of butter washed with alkaline water was higher than that of butter washed with slightly acid water. He states that the butter in the acid solution clumped better than did that in the alkaline solution. The effect of bacteria in the wash water suggested to Melick (1906) the deduction that there is a direct relation between the bacterial content of the wash water used and the keeping quality of the butter.

Kooper-Güstrow (1911) states that butter made from sour cream containing iron rust, has a metallic flavor and a marked grayish color interspersed with dark spots. However, a wash water with an iron content as high as 36 milligrams to 1000 cubic centimeters of water does not affect the quality of the butter.

Rogers and Gray (1909) draw the following conclusions from investigations on pasteurized and on unpasteurized cream of varying amounts of acidity, and on the resulting butter stored at different temperatures:

> Butter frequently undergoes marked changes, even when stored at very low temperatures. These changes are more marked as the acidity of the cream from which the butter is made is increased.
>
> No bacteria were found in the cream or the butter which could reasonably be expected to be the cause of the more rapid deterioration of the high-acid butter.

The changes in the high-acid butter were not checked by heating the ripened cream, which shows that they were not brought about by enzymes secreted with or in the cream and carried into the butter.

Marked changes of an undesirable nature were produced in butter by acidifying pasteurized cream with various acids. These changes did not take place all at once, but were of a progressive nature.

The results indicate that the acid developed normally in the cream by the action of the lactic-acid bacteria, or added directly to the cream in the form of pure acid, brings about or assists in bringing about a slow decomposition of one or more of the labile compounds of which butter is largely composed.

Rogers and his associates (1913) found later that copper sulfate produces fishy flavor in butter. They found also that fishy flavor will develop in cream ripened while in contact with two sheets of copper.

Mortensen, Gaessler, and Cooper (1914) differ with Lee (1909), claiming that pasteurization of either sweet or sour cream improves the flavor of the resulting butter. The protein content of the resulting butter is not influenced by the pasteurization of sweet cream, according to these investigators, but is decreased by the pasteurization of sour cream.

The decomposition of protein in butter during storage has been studied by Brown (1915). He finds that the protein of butter is slowly broken down to amino acids and ammonia. The percentage of total nitrogen in unsalted butter, from the amino acids and ammonia, was found to be 5.71 at first, and 7.59 after the butter had been stored at −6° C. for two hundred and forty days. In the salted butter the amino acids and ammonia increased to 8.19 per cent after a storage period of two hundred and forty days. Hunziker (1916) also found protein hydrolysis in butter during storage, as well as amino acids and other products of decomposition. Hunziker concludes that the initial condition of the cream, the amount of hydrolyzing agents present, and the temperature, determine the degree of hydrolysis.

A new protein, soluble in alcohol, has recently been found in milk by Osborne and Wakeman (1918). It has a phosphorus content, on an ash-free, water-free basis, of 0.08 per cent P. This protein, while soluble in alcohol, is insoluble in dilute acids or in salt solution. The results of the experiments here described seem to show that such a protein exists in butter. In earlier work on phosphatides in milk, Osborne and Wakeman (1915) obtained 116 grams of lecithin from 3000 liters of milk. While they were hydrolyzing a solution of this lecithin with barium sulfate, some of the lecithin was broken down so that trimethylamine was detected in the vapors from the hot solution.

EXPERIMENTAL AND ANALYTICAL RESULTS OF THE PRESENT INVESTIGATION

The butter used in all the experiments here discussed was made from cream containing 30 per cent of butterfat. Seven portions of the cream were churned separately in a barrel churn, operated by hand. The butter, washed and worked in the usual manner, was then divided, one half being packed immediately in porcelain jars, and the other half being salted to a content of 2½ per cent before packing. All samples were then stored in a refrigerator held at −10° C.

Before churning, the seven portions were treated differently, as follows:

Portion 1: To 5 pounds of sweet raw cream there was added 2 ounces of starter — a pure culture of lactic-acid-producing bacteria, in skimmilk. The cream mixture was then held for six hours at room temperature, after which it was placed overnight in a refrigerator at 0° C. The next morning it was removed from the refrigerator, and was brought to a temperature of 15.5° C. by immersing the can in warm water. The mixture had developed an acidity, estimated as lactic acid, of 0.38 per cent. A few drops of butter color were added and the mixture was then churned. The temperature during churning was approximately 15.5° C. After churning, the buttermilk was removed and the butter was washed twice with water at 15.5° C. Each portion of the wash water was equivalent in volume to the buttermilk removed from the churn. In washing the butter, the churn was given only one revolution for each washing. After washing, the butter was removed from the churn with a wooden ladle and was worked for about five minutes in a wooden bowl. It was then divided into two portions, one portion being packed in porcelain jars and the other portion being salted to a content of 2½ per cent. All the samples were labeled, covered with parchment paper, and stored in a refrigerator at −10° C.

Portion 2: The second portion consisted of sweet raw cream which was churned as soon as it was separated from the milk. After churning, the butter in this sample and that in the following samples was treated the same as was the butter from portion 1.

Portion 3: Lactic acid of 25 per cent strength was added to sweet raw cream until the acidity of the cream was 0.38 per cent. The mixture was then heated to 74° C. and held at that temperature for thirty minutes.

The flask containing the cream was then suddenly cooled in water to 15.5° C., and after standing for three hours the cream was churned.

Portion 4: Raw cream was allowed to stand at room temperature until it developed an acidity equivalent to 0.35 per cent, when it was churned. The sample took three days to develop this degree of acidity.

Portion 5: Commercial lactic acid of 25 per cent strength was added to the cream until the acidity of the cream was 0.35 per cent. The portion was thoroughly stirred, quickly brought to a temperature of 15.5° C., and then churned.

Portion 6: Cream was heated in a flask to 74° C. for thirty minutes, was then cooled to 15.5° C., and, after standing for three hours, was churned.

Portion 7: The cream was pasteurized as was portion 6; but instead of being churned after pasteurization, the sample was cooled, was allowed to stand at room temperature for four hours after 4 ounces of liquid starter had been added, and was then placed overnight in a refrigerator at 0° C. After the cream was removed from the refrigerator the next morning, its temperature was raised to 15.5° C. and it was churned immediately. The acidity of the cream at the time of churning was 0.45 per cent.

As may be seen from the above-described methods of treatment of the various portions, the manufacturing methods of treatment of cream before churning were closely followed. The seven methods outlined are the ones most generally employed in the manufacture of butter, and it was with the idea of simulating conditions that would be used in any manufacturing process for butter that these seven portions were treated as described. The different methods employed seem to have varying influences on the phosphorus compounds in the milk and the cream, and also on the churned product during storage.

The phosphorus compounds of milk, which are present also in cream and in butter, are: casein, lecithin, the new protein found by Osborne and Wakeman (1918), and inorganic phosphates. To show the effect on these compounds of the various methods of handling the cream, determinations were made of the organic and the inorganic phosphorus content of the respective butters made from the seven portions of cream.

In an attempt to find a method which would give directly the organic phosphorus in butter, instead of having to obtain it by difference as is the general custom the experiment was made of incorporating the butter

into calcium sulfate and extracting the organic phosphorus compounds with alcohol. The method was as follows: 25 grams of butter was intimately mixed with 150 grams of anhydrous calcium sulfate until all the butter was completely absorbed and the mixture felt dry and powdery to the touch. In some cases a larger quantity of calcium sulfate is necessary to acquire the desired consistency. The mixture was then placed in a large Soxhlet apparatus, a filter paper being used instead of the customary extraction thimble. About 150 cubic centimeters of 95-per-cent alcohol was used as the extracting agent, and the apparatus was run for forty-eight hours. At the end of that time the alcohol was removed, transferred to an Erlenmeyer flask, and evaporated, and the residue,[3] consisting of lecithin, fatty acids, and alcohol-soluble protein, was digested with nitric acid. From this point, method 2 (*b*) in the Methods of Analysis of the Association of Official Agricultural Chemists[4] was used. To the result obtained by the alcoholic extraction is added the per cent of phosphorus obtained from the casein. In making the organic phosphorus determination of the casein, 10 grams of butter was melted and was filtered on a hot funnel, and the filter was washed with three or four portions (30 cubic centimeters each) of 80-per-cent alcohol. The filter paper and its contents were then removed to a 300-cubic-centimeter Erlenmeyer flask with a glass stopper, and were shaken with 75 cubic centimeters of a solution of 0.2-per-cent hydrochloric acid. The supernatant liquid in the flask was then decanted through a dry filter paper, and the extraction of the casein and the filter paper in the Erlenmeyer flask with the acid solution was repeated three times. By this method all the phosphorus compounds of butter, with the exception of the casein, were removed. The new filter was then removed from the funnel and placed in the Erlenmeyer flask with the old filter, and phosphorus determination on the whole was made by the same method as in the case of the alcohol residue. The combined phosphorus results, from the alcohol residue and the casein residue, gave the total organic phosphorus content of the butter.

The low results — 0.0035 and 0.0038 per cent of phosphorus (P_2O_5,) — from the alcoholic residue for total organic phosphorus, seem to indicate that not all the alcohol-soluble phosphorus compounds were extracted. Some,

[3] A test for phosphates must be made on the residue

[4] Official and provisional methods of analysis, Association of Official Agricultural Chemists, p. 3. U. S. Bur Chem, Bul 107 1908

if not all, of the lecithin was extracted, and the alcohol residue showed the presence of protein also. However, since the accuracy of the method was not definitely established, its use in obtaining results in this problem was discontinued; it has nevertheless not been discarded entirely, as further work on the method is contemplated. The author has not been able to find any reference to attempts at the direct separation of organic phosphorus from inorganic phosphorus in butter. Attempts have been made at the direct determination of organic phosphorus in milk, and a direct determination of lecithin in milk has been made by Osborne and Wakeman (1915).

The well-known Hart and Andrews method [5] for determination of soluble organic and soluble inorganic phosphorus was applied in a general way to the extraction of the soluble organic phosphorus and the soluble inorganic phosphorus in butter. The method was as follows: 20 grams of butter was melted in a beaker and washed into a separatory funnel with 50 cubic centimeters of a half-saturated sodium chloride solution which had been heated to about 45° C. The separatory funnel was shaken vigorously, the fat was allowed to separate, and the aqueous part was drawn off and passed through a filter paper into a beaker. Two other extractions were similarly made, about 30 cubic centimeters of the salt solution being used in each case. The salt-water extraction was followed by six washings in 25 cubic centimeters of a warm solution of 0.2-per-cent hydrochloric acid. This method extracted all the soluble inorganic phosphorus and an appreciable amount of the organic phosphorus from the butter. The different fractions of the solvents having been filtered together, the filtrate was then divided into two portions. Total soluble phosphorus was determined on one portion according to the method of the Association of Official Agricultural Chemists. Soluble inorganic phosphorus was determined on the other portion according to the Hart and Andrews method. This was done by immediately neutralizing the solution to slight alkalinity with ammonia, precipitating the soluble inorganic phosphorus with magnesia mixture, allowing it to stand in a cool place for four hours, filtering, and ashing. The ash was redissolved in a small amount of hydrochloric acid and hot water, reprecipitated, filtered, ashed, and weighed as mag-

[5] Hart, E. B., and Andrews, W. H. The status of phosphorus in certain food materials and animal by-products, with special reference to the presence of inorganic forms. Amer. chem. journ. **30**: 470–485. 1903.

nesium pyro-phosphate. The soluble organic phosphorus is then the difference between the total soluble and the soluble inorganic phosphorus.

The protein residue from the salt-water and hydrochloric-acid extractions was placed in a 300-cubic-centimeter Erlenmeyer flask and digested with nitric acid. Total phosphoric acid was determined on this according to the method of the Association of Official Agricultural Chemists. This represented the insoluble organic phosphorus in the protein of the butter.

In a few cases the protein residue from the butter, after extraction with hot salt solution and dilute hydrochloric acid, was extracted on the filter with several portions of warm 80-per-cent alcohol, and separate determinations were made on the alcoholic filtrate and on the residue left on the filter. These results are given in table 6 (page 173). They show that some of the protein is soluble in alcohol.

Results of the first series of experiments are given in table 1. These results show the percentages of total soluble, soluble inorganic, and

TABLE 1. Phosphorus Content of Salted Samples of Butter Made on January 11 and Analyzed on January 28, 1918

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
1	0129	0156	0027	.0123	.0338
2	0138	0168	0030	.0108	0397
3	0100	0121	0024	.0079	.0249
4	0127	0132	0005	0131	.0351
5	0170	0202	0032	0103	.0414
6	.0155	0180	0025	0095	.0344
7	.0108	0124	0016	.0089	0300

soluble organic phosphorus (P_2O_5) in the butter (the last-named obtained by difference), and the percentage of phosphorus in the protein residue. A separate analysis of the total phosphorus content of the portions of butter was made in every case also. The numeral preceding each analysis in the table refers to the portion of cream from which the sample of butter was made.

It is shown by the table that the highest percentage of total phosphorus was retained in the butter when only lactic acid was added and churning

was begun at once (sample 5). There was little difference between this sample of butter and that made from sweet raw cream (sample 2), except that the total soluble phosphorus of sample 5 was greater than that of sample 2. The soluble organic phosphorus content of both was about equal, as were their protein residues also. The only difference in the treatment of the two samples was in the addition of lactic acid to sample 5 before churning. The action of the acid in this case is readily seen in the higher amount of soluble inorganic phosphorus; either there was some splitting-off of phosphorus from some organic phosphorus compound which was heretofore insoluble, or some insoluble phosphates were made soluble by the lactic acid. Sample 4 retained the next highest amount of total phosphorus. This butter was made from raw cream ripened without starter; the acidity developed slowly, at room temperature, at the expense of the lactose. This sample had the greatest amount of phosphorus in the protein residue, however, and the smallest amount of soluble organic phosphorus. The total soluble phosphorus was comparatively very low.

Sample 6, which was made from pasteurized sweet cream, had a total of 0.0344 per cent of phosphorus (P_2O_5). Evidently very little of the organic phosphorus compounds decomposed by heating. The appreciable amount of organic phosphorus seems to be due to the stable condition of the protein and the absence of acid.

Sample 1 was made from raw cream ripened with starter. It had a total phosphorus (P_2O_5) content of 0.0338, and compared very closely with the pasteurized-sweet-cream sample 6, except that its soluble phosphorus was much lower than that of the latter. This difference was made up by the protein residue of sample 1, which was greater in this component by about the same amount as the two samples varied in their soluble phosphorus.

Sample 7 was made from pasteurized cream which was subsequently ripened with starter. It showed a marked depreciation in its total and in its soluble phosphorus. Undoubtedly the heating of the cream during pasteurization rendered many of the phosphorus compounds unstable, so that they were easily broken down by the lactic acid during the long process of ripening before churning. Contrasted with sample 7 is sample 3, which was made from pasteurized sweet cream to which lactic acid had been added. Sample 3 was comparatively low in total phosphorus, due undoubtedly to the high acid content at the time of pasteurization. This proves

that high temperatures, and especially a pasteurizing temperature, accelerate decomposition when acid is present.

The immediate effect of ripening cream with starter showed little decomposition of the phosphorus compounds in the butter, especially in its organic phosphorus content. The sweet raw cream, however, had less splitting-off of phosphorus than had the cream ripened with starter. Raw cream, which was self-ripened, had little soluble organic phosphorus left at the time when it was churned, but later, in storage, the soluble inorganic phosphorus was increased, evidently at the expense of the protein fraction.

The changes that had taken place in the butter samples designated in table 1 after they had been in storage for fifteen months, are shown in table 2. The analyses showed the soluble organic phosphorus to be approaching or to be almost entirely in the inorganic form. The raw

TABLE 2. Phosphorus Content of Same Samples in April, 1919

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
1	.0158	0204	.0046	.0120	
2	0232	0236	0004	0163	
3	0191	.0193	0002	.0086	Totals checked
4	.0157	0168	0011	.0163	
5	0227	.0242	0015	0166	
6	0201	0211	.0010	.0115	
7	.0148	0207	0059	.0091	

cream ripened with starter (sample 1) and the pasteurized cream ripened with starter (sample 7) had retained the greatest amounts of organic phosphorus during storage. The phosphorus content of the protein residue in these samples, however, had not increased, and in this respect they showed a marked contrast to the remaining samples, in all of which the phosphorus in the protein residue had increased from a few milligrams in the pasteurized samples 3 and 6 up to 63 milligrams in the sweet-raw-cream sample treated with lactic acid (sample 5). As is generally understood, pasteurization of the cream destroys enzymes and leaves but few

bacteria to survive in the butter and ultimately to produce acid by fermenting the lactose; and since sample 5 had both acid added to the cream from which it was made, and enzymes and bacteria left undisturbed, it may be concluded that the high phosphorus content in its protein residue was due to insoluble phosphorus compounds formed by these agencies. Another factor which may sustain the theory that high acidity produces insoluble phosphorus compounds is evidenced in sample 2 (sweet raw cream), in which a large proportion of the lactose would have been present in the cream before churning and would therefore have been in reserve for the formation of acid in the butter. The presence of salt also seems to have an effect in increasing the insoluble phosphorus compounds during storage.

Analyses of one unsalted sample are given in table 3, to show the effect of the absence of salt on the phosphorus content of butter during storage.

TABLE 3. PHOSPHORUS CONTENT OF UNSALTED SAMPLE OF BUTTER FROM CREAM PORTION 2

Butter sample	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
Analyzed January 28, 1918....	0158	.0199	0041	.0139	.0468
Analyzed in April, 1919.	.0229	0250	.0021	.0147	....

There was a greater amount of soluble organic and soluble inorganic phosphorus present in this sample, and a larger percentage of phosphorus in the protein residue, than in the salted sample of the same butter. The loss of phosphorus compounds in the salted sample, at this stage of the experiment, was due to the working of the salt into the butter. Later, in storage, there was an increase in the soluble phosphorus, and an appreciable amount of soluble organic phosphorus was present at the end of fifteen months. The protein residue, however, increased its phosphorus content by only a small amount.

Several other samples, duplicates of those designated in table 1 in every respect except that they were not salted, were analyzed and gave results

comparable with those shown in table 3. There were only slight increases in the phosphorus content of the protein residues. This seems to prove that salt is a contributing factor in the production of insoluble phosphorus compounds during the storage of butter. There was in almost every case a larger amount of total phosphorus in the unsalted samples than in the salted ones. As noted above, during the process of salting, the butter loses a small quantity of liquid which carries away with it an appreciable amount of phosphorus compounds.

Another series of experiments, conducted in exactly the same manner as the foregoing, was made about a month later than the first series. The results were almost completely in accord with those of the earlier experiments. These results are given in tables 4 and 5:

TABLE 4. Phosphorus Content of Butter Made on January 31 and Analyzed on February 3, 1918

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
1	0125	.0152	0027	.0133	.0335
2	.0130	.0164	.0031	0100	.0392
3	0106	0138	0032	.0079	.0318
4	0102	.0146	0044	0122	0357
5	0138	0169	.0031	0076	.0398
6	.0137	0167	0030	.0102	.0386
7	0078	0105	.0027	.0069	0243

TABLE 5. Phosphorus Content of Three of the Same Samples in April, 1919

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
3	0191	0190	0000	0092	Totals checked
4	.0199	0199	0000	.0157	
7	.0163	.0170	.0007	.0068	

As the protein residue seemed to be affected by the methods of handling the cream and by pasteurization, it was thought advisable to determine whether all the residue was casein, or whether the casein had adsorbed some phosphorus compound, or a portion thereof, which it released only during pasteurization. To determine this point, the samples of butter were successively treated with half-saturated sodium chloride solution and a solution of 0.2-per-cent hydrochloric acid, as inthe extraction method previously described (page 167). The protein residue on the filter was removed in the filter paper to an Erlenmeyer flask and shaken with 50 cubic centimeters of 80-per-cent alcohol. The alcohol was then decanted through a dry filter into a clean beaker, and two similar extractions were made on the residue in the Erlenmeyer flask. Finally, the residue and the filter were washed with a small quantity of ether. The filter paper was removed to the Erlenmeyer flask and total phosphorus was determined on this. This was the casein portion. The alcohol-ether filtrate was likewise placed in an Erlenmeyer flask and the total contents were evaporated to dryness. Total phosphorus was then determined on this portion also. The results are given in table 6. Samples 2 and 5 (table 1) were made from cream portions 2 and 5, respectively. They were one month old when these results were obtained. Sample 2 (table 4) was made from cream portion 2 in the second series, and was three days old when analyzed. All three samples were unsalted.

TABLE 6. PHOSPHORUS CONTENT OF RESIDUE AS SHOWN BY SEPARATION OF ALCOHOL-SOLUBLE PROTEIN FROM CASEIN

Butter from cream portion	Per cent of P_2O_5	
	Protein residue (alcohol-ether extraction)	Casein residue
2 (table 1)	0030	0077
5 (table 1)	0030	0077
2 (table 4)	0040	0075

The results given in table 6 show that an appreciable amount of organic phosphorus can be extracted from the supposed casein residue by alcohol.

This phosphorus compound did not give the tests for lecithin, nor was it soluble in weak salt solution. No further work was done on this alcohol-soluble phosphorus compound except to obtain a positive test for protein. According to the work of Osborne and Wakeman (1918), it appears to be the new protein found in milk by them.

DISTRIBUTION OF PHOSPHORUS AMONG THE VARIOUS PRODUCTS IN CHURNING

A study was made of the distribution of phosphorus among the various products in the manufacture of butter. Results obtained from churnings in which the cream was not pasteurized and was ripened with starter, are shown in tables 7, 8, and 9.

The history of the sample used for the data given in table 7 was as follows: To 20 pounds of sweet cream from milk recently skimmed, a

TABLE 7. Distribution of Phosphorus Content in Butter Made on February 22, 1919. Analyses Started on the Same Date

	Per cent of P_2O_5			
	Total soluble	Soluble inorganic	Soluble organic	Total
Milk	1387	.1178	0209	.2161
Cream	1033	0902	0131	.1619
Buttermilk	.1222	.1143	0079	.2155
First wash water	.0037	.0031	.0006	.0115
Second wash water	.0000	0000	.0000	0004
Salt water†	.0263	.0251	0012	.0340
Butter	.0191	.0154	.0037	.0485
Washed butter	....	......	....	0089
Extracted butter	......	...	......	.0038

† Only 100 cubic centimeters of salt water was expressed from the butter.

pint of liquid starter was added. The mixture was allowed to stand at room temperature for three hours and was then placed in a refrigerator overnight. The next morning it was removed from the refrigerator and was found to have developed an acidity of 0.48 per cent. It was then churned in the usual manner, was salted, and was stored at a temperature of 0° C. The fat content of the cream at the time of churning was 24.5 per cent. After five months in storage the sample scored 91, which is considered a high score for storage butter.

There was 49.5 per cent of fat in the cream from which the butter used for the data given in table 8 was made. The cream was fairly fresh and was ripened with starter. The acidity of the cream at the time of

TABLE 8. DISTRIBUTION OF PHOSPHORUS CONTENT IN BUTTER MADE ON APRIL 5, 1919. ANALYSES STARTED ON THE SAME DATE

	Per cent of P_2O_5			
	Total soluble	Soluble inorganic	Soluble organic	Total
Cream	0689	.0599	.0090	0905
Buttermilk	1025	0960	.0065	.1657
First wash water	0076	.0058	.0018	0170
Second wash water	0038	0028	.0010	.0050
Salt water*	0163	0153	0010	.....
Butter	.0280	0205	.0075	0325

* Only 10 cubic centimeters of salt water was expressed from the butter.

churning was 0.52 per cent. The salt content of the butter was 3.8 per cent. Only 10 cubic centimeters of salt water was expressed from this butter in working it. The analysis of the first wash water from this churning is given in table 9:

TABLE 9. ANALYSIS OF FIRST WASH WATER FROM BUTTER CHURNING
(From butter used for data given in table 8)

Substance	Per cent
Lactose	0 45
Total solids	0 602
Ash	0 050
Lactoglobulin	Present
Lactalbumin	None

Experiments were made on several portions of the butter used for the data in table 7, to determine the effect of varying amounts of salt on the keeping qualities of the product. The portions were salted so as to give the following salt content: 0.5 per cent, 1 per cent, 2 per cent, 3 per cent, 5 per cent, 7 per cent, 10 per cent, and 15 per cent. A fresh (unsalted) sample also was included in the series. The samples were stored in porce-

lain jars in a refrigerator held at 0° C., and were scored every two weeks for quality. The effect of the various salt concentrations on the soluble phosphorus compounds during the storage period of the butter is shown in table 10:

TABLE 10. Influence of Salt Concentration on Solubility of the Phosphorus Compounds in Butter

(Butter made on February 22, analyzed on May 25, 1919)

Salt concentration	Per cent of P_2O_5		
	Total soluble	Soluble organic	Soluble inorganic
Unsalted	0200	.0041	0159
2 per cent	0280	.0031	.0249
5 per cent	0274	0018	0256
10 per cent	.0255	.0000	.0255
15 per cent	.0242	0000	.0239

The samples of washed and extracted butter shown in table 7 were treated by eliminating from them as far as possible all the salt-soluble compounds, in order to show what would be the effect on the keeping qualities. For the washed butter, 100 grams of the butter was treated on the work board with small amounts of a saturated salt solution until about 300 cubic centimeters of the solution had been used. The salt solution was thoroughly mixed with the butter by means of a wooden ladle, and then drained off. The fat was not melted nor removed from the board at any time until it was finally put into the storage jar. It will be seen that in this sample of butter the phosphorus content was reduced, by washing, from 0.0485 per cent (P_2O_5) to 0.0089 per cent. However, it must be admitted that insoluble matter was carried away in the salt solution by this method.

In the case of the extracted butter, the sample was first treated in the same manner as was the washed butter. It was then melted in an evaporating dish, and the protein and the fat were separated by means of a hot saturated salt solution in a separatory funnel. The salt-water-insoluble residue was caught on a hard filter paper, and the salt water from the repeated salt-water extractions of the fat was used to wash the filter. Finally, the protein residue was scraped from the filter paper and mixed

in a jar with the extracted fat. Enough saturated salt solution was then added to equal the water content of the original butter, and the mixture was stirred, hardened, and stored.

Both these samples, the washed and the extracted, were prepared to demonstrate the possibilities that may occur when butter is overworked, and also to show the effect of the absence of salt-water-soluble compounds on the keeping qualities of butter. The only comment made on either of these samples by the scorers, was that the butter was "tallowy." This was of course due to handling.

No fishy flavor was developed in the samples of butter used for tables 7 and 10, despite the fact that salt is a contributing factor in the development of fishy flavor in butter during storage. As lecithin is soluble in salt solution, the reason for washing and extracting the butter samples was to remove this phosphorus compound and note whether fishy flavor developed in the samples treated in this manner. The samples included in table 10 were used to ascertain whether butter samples of varying salt content would develop fishy flavor more quickly in one salt concentration than in another. These samples were used also to test the influence of the varying salt concentrations on the soluble phosphorus compounds in the butter. No flavor which in any way resembled fishy flavor was detected in any of the samples, but table 10 shows the influence of the various salt concentrations on the soluble phosphorus compounds.

It is the author's opinion, however, that fishy flavor in butter is caused by the decomposition or partial decomposition of the lecithin before churning, and that through the solvent agency of the salt solution the products of decomposition are further broken down in storage to trimethylamine. Trimethylamine may in turn be broken down, or it may be completely adsorbed by some other compound. This latter theory is advanced from the fact that fishy flavor is transitory in some butter.

As evidence of the breaking-down of lecithin in butter during storage, it is only necessary to compare the soluble organic phosphorus content of the butter in table 1 with the soluble organic phosphorus content of the same butter analyzed fifteen months later as shown in table 2. The long period of storage reduced the soluble organic phosphorus almost entirely to the inorganic form in all the samples except 1 and 7, which had a pure lactic acid culture added. Samples 1 and 7 held their soluble organic phosphorus during storage, and there was no decomposition of the organic

phosphorus which became soluble during storage. The lactic-acid bacteria seem to protect the soluble organic phosphorus from decomposition.

Lecithin is soluble in sodium chloride solution, and it is claimed that fishy flavor in butter is caused by the breaking-down of this compound while in solution with salt. The handling of the milk and cream before churning influences the solubility of the lecithin, and its decomposition, both before and after churning, is clearly shown by the records in tables 1 and 2. Its decomposition in butter during storage necessarily follows, as the records show also. Lewkowitsch (1914:802) says, in referring to the lecithin content of butter: "Lecithin has been stated by various observers to occur in butter fat to the extent of 0.017 or even 0.15 to 0.17 per cent (calculated from phosphoric acid). Wrampelmeyer stated 0.007 to 0.033 per cent of lecithin. Jaeckle, however, showed that butter fat contains no compound of phosphorus." These results seem to supply additional proof that lecithin is a variable compound in butter, and give emphasis to the author's conclusions that the methods of handling the milk and cream before churning determine the quantity of lecithin in the resulting butter. Also, the rate at which the lecithin is decomposed during storage is determined by the condition and the handling of the milk and cream before churning. However, the rôle played by *Bacterium lactis acidi* in protecting the soluble organic phosphorus from decomposition is not clearly understood. That some organisms have a specific action on phosphorus compounds has been observed, and a summary of the investigation of this subject is contained herein.

Butter from cream portion	Per cent of P_2O_5				
	NaCl extract, inorganic	NaCl extract, soluble	HCl extract of protein	Protein residue after extraction	Butter-fat residue
1	.0107	.0153	0051	0120	.0022
2	.0179	.0183	0053	.0163	None
3	.0145	.0147	.0046	.0086	Trace
4	.0096	0107	.0061	.0163	Trace
5	0189	.0204	0038	.0089	Trace
6	.0148	.0158	0053	.0115	Trace
7	0087	.0148	.0059	.0091	.0030

Since it may be of interest to some readers to know what amounts of phosphorus were extracted separately by the various extracting agents, table 2 is given in detail on the opposite page.

BACTERIOLOGICAL INVESTIGATION AS TO THE CAUSE OF FISHY FLAVOR IN BUTTER

Since butter contains lecithin — a mononitrogenous monophosphatid — which on decomposition yields glycerophosphoric acid and choline,— the latter further decomposing to methylamine, ammonia, carbon dioxide, and methane,— it can naturally be inferred that the decomposition products of choline are the cause of the fishy flavor found in some butter. Trimethylamine, which tastes and smells like decomposed fish and which is a decomposition product of choline, is believed to cause fishy flavor in butter. And, since both fishy odor and fishy flavor have been produced in butter when the cream from which the butter was made was inoculated, it can only be assumed that the phosphorus compound which decomposes to trimethylamine is broken down or used as pabulum by the bacteria. The bacterium used in the author's experiment was the one isolated by Hammer (1917) from a can of fishy-flavored milk and named *Bacterium ichthyosmius*.

PLAN OF THE EXPERIMENT

Cream containing 30 per cent of butterfat was treated in the following ways:

Portion D: 750 cubic centimeters of sweet cream was pasteurized at 63° C. for thirty minutes, cooled to 9° C., inoculated with 1 cubic centimeter of an aqueous solution of *Bacterium ichthyosmius*, and churned at once.

After churning, the butter in this case and in all the following treatments was divided, one-half being salted and the other half left unsalted. A check sample (uninoculated and salted) was made also, and all three samples were stored at −10° C.

Portion E: Sweet raw cream was inoculated in the same way as was portion D, incubated at 37° C. for three hours, cooled to 15° C., and churned.

Portion K: Sweet cream was inoculated, and was then incubated at 37° C. for three hours. At the end of that period the acidity was neutralized to phenolpthalein with sodium hydroxide, and the sample was cooled to 15.5° C. and then churned.

Portion N: Cream was inoculated, incubated, and neutralized as was portion K. After neutralizing, one ounce of liquid starter was added, and the mixture was allowed to stand at 15.5° C. for three hours and then churned.

Portion R: Cream was inoculated, one ounce of starter was added, and the cream was allowed to stand at room temperature for three hours to ripen. It was then neutralized and churned.

Portion X: Cream was inoculated, incubated at 37° C. for three hours, and cooled to 15.5 C., and one ounce of starter was added. After three hours the cream was churned.

Each portion of cream was thus represented by an unsalted sample and a salted sample of butter inoculated with *Bact. ichthyosmius*, and a check sample (salted) which was not inoculated. These were all stored at -10° C. Every two weeks during a period of eight months, a count was taken of the bacteria in both the inoculated samples from each portion. All three samples from each portion were scored frequently for quality (flavor).

RESULTS

None of the check samples (uninoculated) were scored as fishy. None of the unsalted samples (inoculated) were scored as fishy. The salted sample from portion D (inoculated), made from fresh cream which was pasteurized and then churned at once, was not scored as fishy by any of the four judges. The bacteria count decreased rapidly both in the salted and in the unsalted sample of portion D.

Samples from portion E were not scored as fishy by the judges. The bacteria count on the salted inoculated sample was 120,000,000 at the time when it was churned, and at the end of six months the count was 460,000. The unsalted sample had a count of only a few bacteria at the end of four months.

The score for portion K was as follows:

Judge	Unsalted sample	Salted sample
No. 1	No comment	Metallic
No. 2	No comment	No comment
No. 3	No comment	Fishy
No. 4	No comment	Fishy

The only difference between the treatment of the cream in this portion and that in portion E was in the neutralization of the cream after incubation.

In portion N there was no comment on the quality of the sample of unsalted butter. The salted inoculated sample was accidentally destroyed at the beginning of the fourth month in storage. The writer, however, had scored the sample as fishy a short time before it was destroyed.

Portion R scored as follows:

Judge	Unsalted sample	Salted sample
No. 1	No comment . . .	Fishy
No. 2 . . .	No comment	Oily
No. 3	No comment . . .	Fishy
No. 4 . . .	No comment . .	Fishy

After four months in storage the salted inoculated sample of this portion had a strong fishy odor. At the end of seven months this odor had to some extent disappeared.

The samples from portion X scored as follows:

Judge	Unsalted sample	Salted sample
No. 1.	No comment .	Metallic
No. 2.	No comment	Metallic
No. 3. . .	No comment	Tallowy
No. 4 . .	No comment .	Fishy

The bacteria in the salted sample of portion X numbered several millions even after the sample had been in storage for some months.

In the samples of butter just described, fishy flavor was produced by inoculating the cream with *Bacterium ichthoysmius*. The handling of the cream before churning affected the growth of the bacteria differently in every portion. The sweet-cream butter from portion D decreased in its bacteria count very rapidly, and retained a good flavor after being stored for eight months. Portion D compares fairly closely with portion 6 of the earlier experiments as to the way in which it was treated before

churning. The sample from portion 6 retained a large proportion of its total phosphorus, and the soluble organic phosphorus suffered little decomposition, if any. The butter from portion E may be compared with that from portion 2 of the earlier experiments. The total phosphorus content in sample 2 was very high and the amount of soluble organic phosphorus was large. The samples that were scored as fishy in these experiments (from portions K, R, and X) underwent treatment similar to that of sample 4 in table 1. Sample 4 showed a very small amount of organic phosphorus in the soluble form, and it may be inferred that some of its soluble organic phosphorus had been decomposed. All three samples (K, R, and X) prove that where there is a loss of soluble organic phosphorus, fishy flavor develops in the butter. Sample 4 in table 1 also developed a fishy flavor in storage.

Since it seemed necessary to identify the trimethylamine directly, a sample of butter which had been scored as fishy was selected and the trimethylamine was extracted and identified. The method used was as follows: 100 grams of fishy butter was extracted in a separatory funnel with several portions (about 50 cubic centimeters each) of hot water. The washings were separated from the fat and placed in a liter flask. About 25 cubic centimeters of 1.1 caustic potash solution was added to the contents of the flask, the flask was attached to a condenser, and the solution was heated. The distillate was caught in about 50 cubic centimeters of N/10 sulfuric acid solution. The distillation was continued until the volume of the distillate measured about 200 cubic centimeters. The distillate was then evaporated, on a water bath, to dryness. The residue was taken up with a small quantity of 95-per-cent alcohol and again evaporated to dryness. Dehydrated alcohol was then added to the residue, and the extractions were passed through a filter paper into a clean evaporating dish. Several extractions with alcohol were made, after which the new filtrate was evaporated to dryness on a water bath in a covered hood. The new residue, consisting of trimethylamine sulfate, was dissolved in a small quantity of warm water and the contents of the evaporating dish were washed into a 300-cubic-centimeter Erlenmeyer flask. About 5 cubic centimeters of 1:1 caustic potash solution was added to the contents of the flask, and the whole was distilled into 50 cubic centimeters of N/50 hydrochloric acid. A few drops of the distillate were carefully mixed on a glass slide with a solution of platinic chloride,

and orange-colored crystals, octahedral in shape, were produced. Blank checks on the reagents and the water used showed no evidence of contamination with ammonium or potassium, both of which yield crystals of this type. To check the results, a solution of trimethylamine hydrochloride was prepared for comparison, and this gave results identical to those of the trimethylamine salt obtained from the fishy-flavored butter.

As the experimental data show, when cream is handled in certain ways the organic phosphorus compounds which are soluble in salt solution are decomposed more or less before churning or soon after the resulting butter is placed in storage. The organic phosphorus compound lecithin, which is soluble in sodium chloride solution, represents almost entirely, if not entirely, the soluble phosphorus in the organic form as shown in table 1. This soluble organic phosphorus gradually suffers decomposition, as may be seen in table 2. With the exception of two cases, samples 1 and 7, all the samples that had a significant amount of soluble organic phosphorus suffered decomposition of this component during storage; and in the experiment with *Bacterium ichthyosmius*, the butter which, from the method of handling the cream before churning, could be compared to samples 1 and 7, did not develop the fishy flavor. The butter that did decrease in its soluble organic phosphorus content as shown in tables 1 and 2, may be compared to those samples that became fishy in the inoculation experiment.

This publication deals only with the phosphorus in butter, in its various compounds. However, it is an appreciated fact that there are compounds of other salts, and of calcium especially, which have a marked influence on the keeping qualities of butter. Lactic acid also must play no small part in bringing about chemical changes in butter. Further studies are being made on the keeping qualities of butter as affected by calcium compounds and lactic acid.

SUMMARY

For the experiments described in the foregoing pages, butter was made from cream treated in the following ways: sweet cream ripened with starter; sweet cream churned without starter; lactic acid added to cream and the mixture pasteurized; raw cream self-ripened; lactic acid added to cream and churning begun at once; sweet cream pasteurized and then churned immediately; pasteurized sweet cream ripened with starter.

All the methods of handling had some influence on the phosphorus compounds in the cream and subsequently on the phosphorus compounds in the stored butter. Pasteurization had the most decided influence. When cream containing acid was pasteurized, an appreciable amount of phosphorus was rendered soluble and lost in the buttermilk and the wash waters. Much of this phosphorus evidently came from the insoluble protein residue. Pasteurized sweet cream suffered but little phosphorus loss except in the protein residue. More phosphorus was lost when pasteurized sweet cream was subsequently ripened with starter. In the unpasteurized samples, sweet-raw-cream butter retained the largest amount of phosphorus, butter made from raw cream ripened without starter was next, while butter made with starter ranked third.

After fifteen months the samples were again analyzed, and the analyses showed that the phosphorus in the organic compounds had broken down to the inorganic form. Exceptions to this were in the butter made from raw cream ripened with starter, and in the butter made from pasteurized sweet cream subsequently ripened with starter. With the exception of these two, all the samples increased in the phosphorus content of the protein residue. All samples, without exception, increased in soluble inorganic phosphorus during storage. The organic phosphorus compounds in the unsalted samples were slower to break down than were the organic phosphorus compounds in the corresponding salted samples.

There seems to be plenty of evidence that an alcohol-soluble protein containing phosphorus exists in butter and is closely related to casein.

From the results obtained with the samples of butter containing varying amounts of sodium chloride, it can be inferred that salt has an accelerating action on the solubility of insoluble organic phosphorus compounds.

About two-thirds of the total phosphorus of the cream is retained in the buttermilk, and the remaining one-third is shared by the wash waters, the salt exudates, and the butter. The butter finally retains about one-quarter of the phosphorus originally present in the cream.

After fifteen months in storage, all the phosphorus compounds in the fat could be extracted by shaking in a separatory funnel with half-saturated sodium chloride solution.[6] A 0.2-per-cent solution of hydrochloric acid was found necessary to extract the soluble phosphorus in the protein residue.

[6] Extraction with the aid of centrifugation was not tried on the samples used for table 1.

The substance that produces fishy flavor in butter, is undoubtedly preformed in the cream by the breaking-down of the lecithin. It may be assumed that through the solvent action of salt water and lactic acid, trimethylamine (the constituent giving fishy flavor) is formed from one of these broken-down fractions.

CONCLUSIONS

1. In churning, about one-fourth of the total phosphorus of the cream is retained in the butter made therefrom. The remaining three-fourths is lost in the buttermilk, wash waters, and exudates during the salting process.

2. The methods of treatment of milk and cream before churning have an influence on the amount and the form of phosphorus retained in the butter.

3. In storage the soluble organic phosphorus compounds break down, giving inorganic phosphorus compounds.

4. The methods of treatment of milk and cream before churning determine how soon after storage organic phosphorus compounds will assume the inorganic form.

5. Salt in butter has a marked effect in bringing about protein decomposition during storage, even at a temperature of −10° C.

6. The new protein of milk which is soluble in alcohol exists also in butter.

7. Under certain conditions, bacteria are the controlling factors in bringing about chemical changes in the phosphorus compounds of butter.

8. The breaking-down of lecithin and the forming of trimethylamine is the cause of fishy flavor in butter.

9. When fishy flavor develops in butter there is always an appreciable loss of soluble organic phosphorus.

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PHOSPHORUS IN BUTTER

J. T. CUSICK

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CONTENTS

PHOSPHORUS IN BUTTER

PHOSPHORUS IN BUTTER[1]

J. T. Cusick

For a long time manufacturers of butter, and students of its manufacture, have been searching for a method that would give a product capable of withstanding storage conditions and preserving its original quality. The bulk of the methods investigated have dealt with the way in which the raw material is treated and handled before churning. While this earlier treatment does influence the keeping qualities of the churned product, the chemical changes produced, as evidenced in "off flavors," have been investigated in only a few instances. Bacterial, chemical, and enzymic action on butter during its period of storage have been studied almost entirely from the manufacturer's viewpoint, but the results of the methods used by the manufacturer have led to no definite conclusions as to the chemical changes produced by the various manufacturing processes. It is, therefore, with the view of adding some information to present knowledge of the chemical changes occurring in butter during storage, that the rôle played by phosphorus is discussed here. It is clearly shown that the various methods of handling the raw material, and the ways in which it is treated by the manufacturer before churning, have a pronounced influence on the phosphorus in its various forms. One cannot properly interpret "off flavors" and the like without knowing, first, what constituents undergo change, and secondly, what products of decomposition are formed and by what agents.

REVIEW OF LITERATURE

Friis (1897)[2] states that pasteurization of milk or cream appreciably decreases the content of free fatty acids in the resulting butter. His experiments show that

> the amount of free acids in the butter is greatly decreased when the milk or the cream is heated previous to the churning; pasteurization of the milk reduces the free fatty acid content of the fat more than pasteurization of the cream. About half the acidity of fresh sour-cream butter is due to free fatty acids in the butter, and the other half to the acidity of the buttermilk remaining in the butter.

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[1] Also presented to the Faculty of the Graduate School of Cornell University, December, 1919, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy

The work here described was done in the Department of Agricultural Chemistry of the New York State College of Agriculture at Cornell University, under [illegible] George W. Cavanaugh.

[2] Dates in parenthesis refer to *Literature Cited*, page 180.

Schmidt (1898) found that pasteurization of the cream at high temperatures, and salting of the butter, lowered the acidity and the number of bacteria in the butter. Salted butter did not become rancid as soon as did unsalted butter, in his experiments.

Fishy flavor in butter is due to a bacterium, according to O'Callaghan (1902), and is remedied by pasteurization. This theory of the cause of fishy flavor is denied by many investigators, who claim that the flavor is due to enzymic or chemical decomposition.

Steiner (1901) states that pasteurization gives as high a loss of albumin in the butter as 82.5 per cent. The amount of loss depends on the temperature at which the milk is heated and on the time of heating.

Harcourt (1903) found that the amount of nitrogenous matter in butter does not affect its keeping quality.

A primarily practical viewpoint of the question was taken by Lee (1909), who conducted pasteurizing experiments on "farm-skimmed" cream. He concluded that pasteurizing does not affect the body, or texture, of butter, and does not improve the quality of butter made from sour "farm-skimmed" cream.

According to Sayer, Rahn, and Farrand (1908), the use of starter in preparing cream for churning has a decided influence on the butter. Pure cultures of starter gave butter of a high score, according to these investigators. Lindsey (1908) placed great emphasis on care in the quality of the starter to be used, and found that the flavor of butter depends primarily on the cleanliness of the milk, the stage of lactation of the animal, the skill and care of the butter maker, and, especially, the character of the starter employed. He concluded also that normal foodstuffs must be considered of secondary importance in establishing butter flavor.

McKay and Bower (1908) studied the moisture content of butter as it affects the quality of the product. Their efforts led them to conclude that high water content between 15 and 16 per cent does not necessarily mean a low score, nor does less than 13 per cent mean a high score.

Rogers and Gray (1909) made butter from pasteurized and from unpasteurized cream of varying degrees of acidity, and stored it at temperatures of 32°, 10°, and −10° F. They state:

The butter made from unripened unpasteurized cream always developed a cheesy or rancid flavor. The butter made from ripened cream, both pasteurized and unpasteurized, developed cold-storage, fishy, and other flavors typical of storage butter. In all cases the overripe butter showed marked deterioration. The butter made from pasteurized cream

without starter usually retained its flavor with little or no change. Even at 32° F. the sweet-cream butter deteriorated very little ...

Butter made from pasteurized cream with starter added, . . . retained its fresh flavor better than the ripened-cream butter, but was not quite equal in keeping quality to that made from sweet pasteurized cream.

High acidity reduces the keeping quality, according to these workers.

Melick (1909: 281) found that "the use of commercial lactic acid as a substitute for starter proved advantageous only when used in very rancid cream....."

Saponification of the butterfat takes place during storage, according to Vincent (1910), increasing the insoluble fatty acids. The soluble and the insoluble fatty acids are formed directly by decomposition and by synthesis, respectively. It is evident that the glycerides of the insoluble acids are changed to a greater degree than are those of the soluble acids. Vincent found also that glycerol is present in old butter and in old cream, but not in milk.

During experiments in the manufacture of butter and cheese, Dean (1910) found that when 10 per cent of starter was added to cream for making butter, there was a greater loss of fat in the pasteurized than in the raw cream. This loss increased with the increase of acidity in the cream at the time of pasteurization. There was little difference in the quality of fresh butter when pasteurized at different temperatures, but the keeping quality was improved by pasteurizing the cream at a temperature between 60° and 82° F.

Larsen, Lund, and Miller (1910) found that the acidity of thoroughly washed butter at the time of making was less than that of butter that was washed but little, by the equivalent of 0.3 cubic centimeter of N/10 alkali to 10 grams of butter. At the end of sixteen weeks this difference had increased to only 0.5 cubic centimeter. Butter made from pasteurized cream did not increase in acidity as rapidly as did butter made from raw cream. The average difference between the two samples immediately after churning was only 0.1 cubic centimeter, but after the butter had been kept in storage for sixteen weeks this difference had increased to 1.1 cubic centimeters. During the sixteen weeks the acidity of the pasteurized-cream butter had increased only 0.6 cubic centimeter, as compared with an increased acidity of 1.6 cubic centimeters in the raw-cream butter. The acidity in lightly salted butter increased by 4.7 cubic centimeters in sixteen weeks, as compared with an increase of 1.6 cubic centimeters

for heavily salted butter. The acidity of ripened-cream butter increased more than did the acidity of sweet-cream butter. The bulletin states (page 715):

These results indicate that butter from fresh and properly ripened cream not over one day old keeps better than does butter made from sweet cream. The butter fat from very fresh cream is apparently in a more stable condition than is the fat in the sour cream over one day old, and not so predisposed to decomposition. It indicates that butterfat, in the form of butter, keeps better than does butterfat in the form of cream, even though it be in properly ripened cream.

It has been found by Rahn, Brown, and Smith (1909) that there is very little loss of lactose during the storage of butter, and apparently little or no relation between the water-soluble acids and the amount of lactose lost. The butter having the highest initial scores showed the least change in its amino nitrogen content. Butter scoring a little lower and made from cream of a poor quality showed an increased decomposition of protein. The butter with the lowest score yielded the largest amount of protein cleavage products.

The influence of the alkalinity of the wash water was investigated by Meijeringh (1911). He found that the water content of butter washed with alkaline water was higher than that of butter washed with slightly acid water. He states that the butter in the acid solution clumped better than did that in the alkaline solution. The effect of bacteria in the wash water suggested to Melick (1906) the deduction that there is a direct relation between the bacterial content of the wash water used and the keeping quality of the butter.

Kooper-Güstrow (1911) states that butter made from sour cream containing iron rust, has a metallic flavor and a marked grayish color interspersed with dark spots. However, a wash water with an iron content as high as 36 milligrams to 1000 cubic centimeters of water does not affect the quality of the butter.

Rogers and Gray (1909) draw the following conclusions from investigations on pasteurized and on unpasteurized cream of varying amounts of acidity, and on the resulting butter stored at different temperatures:

Butter frequently undergoes marked changes, even when stored at very low temperatures. These changes are more marked as the acidity of the cream from which the butter is made is increased.

No bacteria were found in the cream or the butter which could reasonably be expected to be the cause of the more rapid deterioration of the high-acid butter.

The changes in the high-acid butter were not checked by heating the ripened cream, which shows that they were not brought about by enzymes secreted with or in the cream and carried into the butter.

Marked changes of an undesirable nature were produced in butter by acidifying pasteurized cream with various acids. These changes did not take place all at once, but were of a progressive nature.

The results indicate that the acid developed normally in the cream by the action of the lactic-acid bacteria, or added directly to the cream in the form of pure acid, brings about or assists in bringing about a slow decomposition of one or more of the labile compounds of which butter is largely composed.

Rogers and his associates (1913) found later that copper sulfate produces fishy flavor in butter. They found also that fishy flavor will develop in cream ripened while in contact with two sheets of copper.

Mortensen, Gaessler, and Cooper (1914) differ with Lee (1909), claiming that pasteurization of either sweet or sour cream improves the flavor of the resulting butter. The protein content of the resulting butter is not influenced by the pasteurization of sweet cream, according to these investigators, but is decreased by the pasteurization of sour cream.

The decomposition of protein in butter during storage has been studied by Brown (1915). He finds that the protein of butter is slowly broken down to amino acids and ammonia. The percentage of total nitrogen in unsalted butter, from the amino acids and ammonia, was found to be 5.71 at first, and 7.59 after the butter had been stored at -6° C. for two hundred and forty days. In the salted butter the amino acids and ammonia increased to 8.19 per cent after a storage period of two hundred and forty days. Hunziker (1916) also found protein hydrolysis in butter during storage, as well as amino acids and other products of decomposition. Hunziker concludes that the initial condition of the cream, the amount of hydrolyzing agents present, and the temperature, determine the degree of hydrolysis.

A new protein, soluble in alcohol, has recently been found in milk by Osborne and Wakeman (1918). It has a phosphorus content, on an ash-free, water-free basis, of 0.08 per cent P. This protein, while soluble in alcohol, is insoluble in dilute acids or in salt solution. The results of the experiments here described seem to show that such a protein exists in butter. In earlier work on phosphatides in milk, Osborne and Wakeman (1915) obtained 116 grams of lecithin from 3000 liters of milk. While they were hydrolyzing a solution of this lecithin with barium sulfate, some of the lecithin was broken down so that trimethylamine was detected in the vapors from the hot solution.

EXPERIMENTAL AND ANALYTICAL RESULTS OF THE PRESENT INVESTIGATION

The butter used in all the experiments here discussed was made from cream containing 30 per cent of butterfat. Seven portions of the cream were churned separately in a barrel churn, operated by hand. The butter, washed and worked in the usual manner, was then divided, one half being packed immediately in porcelain jars, and the other half being salted to a content of $2\frac{1}{2}$ per cent before packing. All samples were then stored in a refrigerator held at −10° C.

Before churning, the seven portions were treated differently, as follows:

Portion 1: To 5 pounds of sweet raw cream there was added 2 ounces of starter — a pure culture of lactic-acid-producing bacteria, in skim-milk. The cream mixture was then held for six hours at room temperature, after which it was placed overnight in a refrigerator at 0° C. The next morning it was removed from the refrigerator, and was brought to a temperature of 15.5° C. by immersing the can in warm water. The mixture had developed an acidity, estimated as lactic acid, of 0.38 per cent. A few drops of butter color were added and the mixture was then churned. The temperature during churning was approximately 15.5° C. After churning, the buttermilk was removed and the butter was washed twice with water at 15.5° C. Each portion of the wash water was equivalent in volume to the buttermilk removed from the churn. In washing the butter, the churn was given only one revolution for each washing. After washing, the butter was removed from the churn with a wooden ladle and was worked for about five minutes in a wooden bowl. It was then divided into two portions, one portion being packed in porcelain jars and the other portion being salted to a content of $2\frac{1}{2}$ per cent. All the samples were labeled, covered with parchment paper, and stored in a refrigerator at −10° C.

Portion 2: The second portion consisted of sweet raw cream which was churned as soon as it was separated from the milk. After churning, the butter in this sample and that in the following samples was treated the same as was the butter from portion 1.

Portion 3: Lactic acid of 25 per cent strength was added to sweet raw cream until the acidity of the cream was 0.38 per cent. The mixture was then heated to 74° C. and held at that temperature for thirty minutes.

The flask containing the cream was then suddenly cooled in water to 15.5° C., and after standing for three hours the cream was churned.

Portion 4: Raw cream was allowed to stand at room temperature until it developed an acidity equivalent to 0.35 per cent, when it was churned. The sample took three days to develop this degree of acidity.

Portion 5: Commercial lactic acid of 25 per cent strength was added to the cream until the acidity of the cream was 0.35 per cent. The portion was thoroughly stirred, quickly brought to a temperature of 15.5° C., and then churned.

Portion 6: Cream was heated in a flask to 74° C. for thirty minutes, was then cooled to 15.5° C., and, after standing for three hours, was churned.

Portion 7: The cream was pasteurized as was portion 6; but instead of being churned after pasteurization, the sample was cooled, was allowed to stand at room temperature for four hours after 4 ounces of liquid starter had been added, and was then placed overnight in a refrigerator at 0° C. After the cream was removed from the refrigerator the next morning, its temperature was raised to 15.5° C. and it was churned immediately. The acidity of the cream at the time of churning was 0.45 per cent.

As may be seen from the above-described methods of treatment of the various portions, the manufacturing methods of treatment of cream before churning were closely followed. The seven methods outlined are the ones most generally employed in the manufacture of butter, and it was with the idea of simulating conditions that would be used in any manufacturing process for butter that these seven portions were treated as described. The different methods employed seem to have varying influences on the phosphorus compounds in the milk and the cream, and also on the churned product during storage.

The phosphorus compounds of milk, which are present also in cream and in butter, are: casein, lecithin, the new protein found by Osborne and Wakeman (1918), and inorganic phosphates. To show the effect on these compounds of the various methods of handling the cream, determinations were made of the organic and the inorganic phosphorus content of the respective butters made from the seven portions of cream.

In an attempt to find a method which would give directly the organic phosphorus in butter, instead of having to obtain it by difference as is the general custom the experiment was made of incorporating the butter

into calcium sulfate and extracting the organic phosphorus compounds with alcohol. The method was as follows: 25 grams of butter was intimately mixed with 150 grams of anhydrous calcium sulfate until all the butter was completely absorbed and the mixture felt dry and powdery to the touch. In some cases a larger quantity of calcium sulfate is necessary to acquire the desired consistency. The mixture was then placed in a large Soxhlet apparatus, a filter paper being used instead of the customary extraction thimble. About 150 cubic centimeters of 95-per-cent alcohol was used as the extracting agent, and the apparatus was run for forty-eight hours. At the end of that time the alcohol was removed, transferred to an Erlenmeyer flask, and evaporated, and the residue,[3] consisting of lecithin, fatty acids, and alcohol-soluble protein, was digested with nitric acid. From this point, method 2 (*b*) in the Methods of Analysis of the Association of Official Agricultural Chemists[4] was used. To the result obtained by the alcoholic extraction is added the per cent of phosphorus obtained from the casein. In making the organic phosphorus determination of the casein, 10 grams of butter was melted and was filtered on a hot funnel, and the filter was washed with three or four portions (30 cubic centimeters each) of 80-per-cent alcohol. The filter paper and its contents were then removed to a 300-cubic-centimeter Erlenmeyer flask with a glass stopper, and were shaken with 75 cubic centimeters of a solution of 0.2-per-cent hydrochloric acid. The supernatant liquid in the flask was then decanted through a dry filter paper, and the extraction of the casein and the filter paper in the Erlenmeyer flask with the acid solution was repeated three times. By this method all the phosphorus compounds of butter, with the exception of the casein, were removed. The new filter was then removed from the funnel and placed in the Erlenmeyer flask with the old filter, and phosphorus determination on the whole was made by the same method as in the case of the alcohol residue. The combined phosphorus results, from the alcohol residue and the casein residue, gave the total organic phosphorus content of the butter.

The low results — 0.0035 and 0.0038 per cent of phosphorus (P_2O_5,) — from the alcoholic residue for total organic phosphorus, seem to indicate that not all the alcohol-soluble phosphorus compounds were extracted. Some,

[3] A test for phosphates must be made on the residue.
[4] Official and provisional methods of analysis, Association of Official Agricultural Chemists, p. 3. U. S. Bur. Chem., Bul. 107. 1908.

if not all, of the lecithin was extracted, and the alcohol residue showed the presence of protein also. However, since the accuracy of the method was not definitely established, its use in obtaining results in this problem was discontinued; it has nevertheless not been discarded entirely, as further work on the method is contemplated. The author has not been able to find any reference to attempts at the direct separation of organic phosphorus from inorganic phosphorus in butter. Attempts have been made at the direct determination of organic phosphorus in milk, and a direct determination of lecithin in milk has been made by Osborne and Wakeman (1915).

The well-known Hart and Andrews method[5] for determination of soluble organic and soluble inorganic phosphorus was applied in a general way to the extraction of the soluble organic phosphorus and the soluble inorganic phosphorus in butter. The method was as follows: 20 grams of butter was melted in a beaker and washed into a separatory funnel with 50 cubic centimeters of a half-saturated sodium chloride solution which had been heated to about 45° C. The separatory funnel was shaken vigorously, the fat was allowed to separate, and the aqueous part was drawn off and passed through a filter paper into a beaker. Two other extractions were similarly made, about 30 cubic centimeters of the salt solution being used in each case. The salt-water extraction was followed by six washings in 25 cubic centimeters of a warm solution of 0.2-per-cent hydrochloric acid. This method extracted all the soluble inorganic phosphorus and an appreciable amount of the organic phosphorus from the butter. The different fractions of the solvents having been filtered together, the filtrate was then divided into two portions. Total soluble phosphorus was determined on one portion according to the method of the Association of Official Agricultural Chemists. Soluble inorganic phosphorus was determined on the other portion according to the Hart and Andrews method. This was done by immediately neutralizing the solution to slight alkalinity with ammonia, precipitating the soluble inorganic phosphorus with magnesia mixture, allowing it to stand in a cool place for four hours, filtering, and ashing. The ash was redissolved in a small amount of hydrochloric acid and hot water, reprecipitated, filtered, ashed, and weighed as mag-

[5] Hart, E. B., and Andrews, W. H. The status of phosphorus in certain food materials and animal by-products, with special reference to the presence of inorganic forms. Amer. chem. journ. 30. 470–485 1903.

nesium pyro-phosphate. The soluble organic phosphorus is then the difference between the total soluble and the soluble inorganic phosphorus.

The protein residue from the salt-water and hydrochloric-acid extractions was placed in a 300-cubic-centimeter Erlenmeyer flask and digested with nitric acid. Total phosphoric acid was determined on this according to the method of the Association of Official Agricultural Chemists. This represented the insoluble organic phosphorus in the protein of the butter.

In a few cases the protein residue from the butter, after extraction with hot salt solution and dilute hydrochloric acid, was extracted on the filter with several portions of warm 80-per-cent alcohol, and separate determinations were made on the alcoholic filtrate and on the residue left on the filter. These results are given in table 6 (page 173). They show that some of the protein is soluble in alcohol.

Results of the first series of experiments are given in table 1. These results show the percentages of total soluble, soluble inorganic, and

TABLE 1. PHOSPHORUS CONTENT OF SALTED SAMPLES OF BUTTER MADE ON JANUARY 11 AND ANALYZED ON JANUARY 28, 1918

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
1	0129	.0156	.0027	0123	.0338
2	0138	0168	0030	0108	.0397
3	0100	0121	0024	0079	.0249
4	.0127	0132	0005	.0131	.0351
5	0170	.0202	.0032	.0103	.0414
6	0155	.0180	.0025	0095	.0344
7	0108	.0124	.0016	0089	0300

soluble organic phosphorus (P_2O_5) in the butter (the last-named obtained by difference), and the percentage of phosphorus in the protein residue. A separate analysis of the total phosphorus content of the portions of butter was made in every case also. The numeral preceding each analysis in the table refers to the portion of cream from which the sample of butter was made.

It is shown by the table that the highest percentage of total phosphorus was retained in the butter when only lactic acid was added and churning

was begun at once (sample 5). There was little difference between this sample of butter and that made from sweet raw cream (sample 2), except that the total soluble phosphorus of sample 5 was greater than that of sample 2. The soluble organic phosphorus content of both was about equal, as were their protein residues also. The only difference in the treatment of the two samples was in the addition of lactic acid to sample 5 before churning. The action of the acid in this case is readily seen in the higher amount of soluble inorganic phosphorus; either there was some splitting-off of phosphorus from some organic phosphorus compound which was heretofore insoluble, or some insoluble phosphates were made soluble by the lactic acid. Sample 4 retained the next highest amount of total phosphorus. This butter was made from raw cream ripened without starter; the acidity developed slowly, at room temperature, at the expense of the lactose. This sample had the greatest amount of phosphorus in the protein residue, however, and the smallest amount of soluble organic phosphorus. The total soluble phosphorus was comparatively very low.

Sample 6, which was made from pasteurized sweet cream, had a total of 0.0344 per cent of phosphorus (P_2O_5). Evidently very little of the organic phosphorus compounds decomposed by heating. The appreciable amount of organic phosphorus seems to be due to the stable condition of the protein and the absence of acid.

Sample 1 was made from raw cream ripened with starter. It had a total phosphorus (P_2O_5) content of 0.0338, and compared very closely with the pasteurized-sweet-cream sample 6, except that its soluble phosphorus was much lower than that of the latter. This difference was made up by the protein residue of sample 1, which was greater in this component by about the same amount as the two samples varied in their soluble phosphorus.

Sample 7 was made from pasteurized cream which was subsequently ripened with starter. It showed a marked depreciation in its total and in its soluble phosphorus. Undoubtedly the heating of the cream during pasteurization rendered many of the phosphorus compounds unstable, so that they were easily broken down by the lactic acid during the long process of ripening before churning. Contrasted with sample 7 is sample 3, which was made from pasteurized sweet cream to which lactic acid had been added. Sample 3 was comparatively low in total phosphorus, due undoubtedly to the high acid content at the time of pasteurization. This proves

that high temperatures, and especially a pasteurizing temperature, accelerate decomposition when acid is present.

The immediate effect of ripening cream with starter showed little decomposition of the phosphorus compounds in the butter, especially in its organic phosphorus content. The sweet raw cream, however, had less splitting-off of phosphorus than had the cream ripened with starter. Raw cream, which was self-ripened, had little soluble organic phosphorus left at the time when it was churned, but later, in storage, the soluble inorganic phosphorus was increased, evidently at the expense of the protein fraction.

The changes that had taken place in the butter samples designated in table 1 after they had been in storage for fifteen months, are shown in table 2. The analyses showed the soluble organic phosphorus to be approaching or to be almost entirely in the inorganic form. The raw

TABLE 2. Phosphorus Content of Same Samples in April, 1919

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
1	.0158	0204	.0046	.0120	Totals checked
2	.0232	.0236	.0004	0163	
3	.0191	.0193	0002	0086	
4	0157	0168	0011	.0163	
5	.0227	.0242	.0015	.0166	
6	.0201	0211	.0010	.0115	
7	0148	0207	0059	.0091	

cream ripened with starter (sample 1) and the pasteurized cream ripened with starter (sample 7) had retained the greatest amounts of organic phosphorus during storage. The phosphorus content of the protein residue in these samples, however, had not increased, and in this respect they showed a marked contrast to the remaining samples, in all of which the phosphorus in the protein residue had increased from a few milligrams in the pasteurized samples 3 and 6 up to 63 milligrams in the sweet-raw-cream sample treated with lactic acid (sample 5). As is generally understood, pasteurization of the cream destroys enzymes and leaves but few

bacteria to survive in the butter and ultimately to produce acid by fermenting the lactose; and since sample 5 had both acid added to the cream from which it was made, and enzymes and bacteria left undisturbed, it may be concluded that the high phosphorus content in its protein residue was due to insoluble phosphorus compounds formed by these agencies. Another factor which may sustain the theory that high acidity produces insoluble phosphorus compounds is evidenced in sample 2 (sweet raw cream), in which a large proportion of the lactose would have been present in the cream before churning and would therefore have been in reserve for the formation of acid in the butter. The presence of salt also seems to have an effect in increasing the insoluble phosphorus compounds during storage.

Analyses of one unsalted sample are given in table 3, to show the effect of the absence of salt on the phosphorus content of butter during storage.

TABLE 3. PHOSPHORUS CONTENT OF UNSALTED SAMPLE OF BUTTER FROM CREAM PORTION 2

Butter sample	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
Analyzed January 28, 1918...	0158	0199	.0041	.0139	.0468
Analyzed in April, 1919 . .	.0229	0250	.0021	0147	....

There was a greater amount of soluble organic and soluble inorganic phosphorus present in this sample, and a larger percentage of phosphorus in the protein residue, than in the salted sample of the same butter. The loss of phosphorus compounds in the salted sample, at this stage of the experiment, was due to the working of the salt into the butter. Later, in storage, there was an increase in the soluble phosphorus, and an appreciable amount of soluble organic phosphorus was present at the end of fifteen months. The protein residue, however, increased its phosphorus content by only a small amount.

Several other samples, duplicates of those designated in table 1 in every respect except that they were not salted, were analyzed and gave results

comparable with those shown in table 3. There were only slight increases in the phosphorus content of the protein residues. This seems to prove that salt is a contributing factor in the production of insoluble phosphorus compounds during the storage of butter. There was in almost every case a larger amount of total phosphorus in the unsalted samples than in the salted ones. As noted above, during the process of salting, the butter loses a small quantity of liquid which carries away with it an appreciable amount of phosphorus compounds.

Another series of experiments, conducted in exactly the same manner as the foregoing, was made about a month later than the first series. The results were almost completely in accord with those of the earlier experiments. These results are given in tables 4 and 5:

TABLE 4. PHOSPHORUS CONTENT OF BUTTER MADE ON JANUARY 31 AND ANALYZED ON FEBRUARY 3, 1918

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
1	.0125	0152	.0027	.0133	0335
2	.0130	.0164	.0034	0100	0392
3	.0106	.0138	.0032	.0079	.0318
4	.0102	.0146	0044	.0122	.0357
5	.0138	.0169	0031	.0076	.0398
6	.0137	.0167	0030	0102	.0386
7	0078	.0105	.0027	.0069	.0243

TABLE 5. PHOSPHORUS CONTENT OF THREE OF THE SAME SAMPLES IN APRIL, 1919

Butter from cream portion	Per cent of P_2O_5				
	Soluble inorganic	Total soluble	Soluble organic	In protein residue	Total
3	0191	0190	0000	0092	Totals checked
4	0199	.0199	0000	.0157	
7	.0163	.0170	0007	.0068	

As the protein residue seemed to be affected by the methods of handling the cream and by pasteurization, it was thought advisable to determine whether all the residue was casein, or whether the casein had adsorbed some phosphorus compound, or a portion thereof, which it released only during pasteurization. To determine this point, the samples of butter were successively treated with half-saturated sodium chloride solution and a solution of 0.2-per-cent hydrochloric acid, as inthe extraction method previously described (page 167). The protein residue on the filter was removed in the filter paper to an Erlenmeyer flask and shaken with 50 cubic centimeters of 80-per-cent alcohol. The alcohol was then decanted through a dry filter into a clean beaker, and two similar extractions were made on the residue in the Erlenmeyer flask. Finally, the residue and the filter were washed with a small quantity of ether. The filter paper was removed to the Erlenmeyer flask and total phosphorus was determined on this. This was the casein portion. The alcohol-ether filtrate was likewise placed in an Erlenmeyer flask and the total contents were evaporated to dryness. Total phosphorus was then determined on this portion also. The results are given in table 6. Samples 2 and 5 (table 1) were made from cream portions 2 and 5, respectively. They were one month old when these

TABLE 6. PHOSPHORUS CONTENT OF RESIDUE AS SHOWN BY SEPARATION OF ALCOHOL-SOLUBLE PROTEIN FROM CASEIN

Butter from cream portion	Per cent of P_2O_5	
	Protein residue (alcohol-ether extraction)	Casein residue
2 (table 1)	0030	.0077
5 (table 1)	0030	0077
2 (table 4)	0040	0075

results were obtained. Sample 2 (table 4) was made from cream portion 2 in the second series, and was three days old when analyzed. All three samples were unsalted.

The results given in table 6 show that an appreciable amount of organic phosphorus can be extracted from the supposed casein residue by alcohol.

phosphorus con.pound did not give the tests for lecithin, nor was ıble in weak salt solution. No further work was done on this alcohol-le phosphorus compound except to obtain a positive test for protein. ·ding to the work of Osborne and Wakeman (1918), it appears to e new protein found in milk by them.

ISTRIBUTION OF PHOSPHORUS AMONG THE VARIOUS PRODUCTS IN CHURNING

study was made of the distribution of phosphorus among the various ıcts in the manufacture of butter. Results obtained from churnings ıich the cream was not pasteurized and was ripened with starter, are n in tables 7, 8, and 9.

e history of the sample used for the data given in table 7 was as vs: To 20 pounds of sweet cream from milk recently skimmed, a

E 7. DISTRIBUTION OF PHOSPHORUS CONTENT IN BUTTER MADE ON FEBRUARY 22, 1919. ANALYSES STARTED ON THE SAME DATE

	Per cent of P_2O_5			
	Total soluble	Soluble inorganic	Soluble organic	Total
ı....	.1387	.1178	0209	.2161
ı....	.1033	.0902	.0131	.1619
·milk.....	.1222	.1143	0079	.2155
vash water..	.0037	0031	.0006	.0115
l wash water	.0000	0000	0000	.0004
ater*...	.0263	.0251	0012	.0340
·.......	.0191	.0154	.0037	.0485
:d butter........	....	....	....	.0089
:ted butter.....	....	....	....	.0038

ly 100 cubic centimeters of salt water was expressed from the butter.

of liquid starter was added. The mixture was allowed to stand at temperature for three hours and was then placed in a refrigerator ıight. The next morning it was removed from the refrigerator and found to have developed an acidity of 0.48 per cent. It was then ned in the usual manner, was salted, and was stored at a temperature C. The fat content of the cream at the time of churning was 24.5 :ent. After five months in storage the sample scored 91, which is dered a high score for storage butter.

There was 49.5 per cent of fat in the cream from which the butter used for the data given in table 8 was made. The cream was fairly fresh and was ripened with starter. The acidity of the cream at the time of

TABLE 8. DISTRIBUTION OF PHOSPHORUS CONTENT IN BUTTER MADE ON APRIL 5, 1919. ANALYSES STARTED ON THE SAME DATE

	Per cent of P_2O_5			
	Total soluble	Soluble inorganic	Soluble organic	Total
Cream	.0689	0599	0090	0905
Buttermilk	1025	0960	0065	.1657
First wash water	0076	.0058	0018	0170
Second wash water	0038	0028	0010	.0050
Salt water*	0163	0153	0010	......
Butter	0280	0205	0075	0325

* Only 10 cubic centimeters of salt water was expressed from the butter.

churning was 0.52 per cent. The salt content of the butter was 3.8 per cent. Only 10 cubic centimeters of salt water was expressed from this butter in working it. The analysis of the first wash water from this churning is given in table 9:

TABLE 9. ANALYSIS OF FIRST WASH WATER FROM BUTTER CHURNING
(From butter used for data given in table 8)

Substance	Per cent
Lactose	0.45
Total solids	0 602
Ash	0 050
Lactoglobulin	Present
Lactalbumin	None

Experiments were made on several portions of the butter used for the data in table 7, to determine the effect of varying amounts of salt on the keeping qualities of the product. The portions were salted so as to give the following salt content: 0.5 per cent, 1 per cent, 2 per cent, 3 per cent, 5 per cent, 7 per cent, 10 per cent, and 15 per cent. A fresh (unsalted) sample also was included in the series. The samples were stored in porc

ain jars in a refrigerator held at 0° C., and were scored every two weeks or quality. The effect of the various salt concentrations on the soluble hosphorus compounds during the storage period of the butter is shown n table 10:

ABLE 10. INFLUENCE OF SALT CONCENTRATION ON SOLUBILITY OF THE PHOSPHORUS COMPOUNDS IN BUTTER

(Butter made on February 22, analyzed on May 25, 1919)

Salt concentration	Per cent of P_2O_5		
	Total soluble	Soluble organic	Soluble inorganic
Jnsalted	.0200	.0011	0159
per cent	0280	.0031	.0249
per cent	0271	0018	.0256
0 per cent	0255	.0000	0255
.5 per cent	0212	.0000	.0239

The samples of washed and extracted butter shown in table 7 were reated by eliminating from them as far as possible all the salt-soluble compounds, in order to show what would be the effect on the keeping qualities. For the washed butter, 100 grams of the butter was treated on the work board with small amounts of a saturated salt solution until about 300 cubic centimeters of the solution had been used. The salt solution was thoroughly mixed with the butter by means of a wooden adle, and then drained off. The fat was not melted nor removed from the board at any time until it was finally put into the storage jar. It will be seen that in this sample of butter the phosphorus content was reduced, by washing, from 0.0485 per cent (P_2O_5) to 0.0089 per cent. However, t must be admitted that insoluble matter was carried away in the salt solution by this method.

In the case of the extracted butter, the sample was first treated in the same manner as was the washed butter. It was then melted in an evaporating dish, and the protein and the fat were separated by means of a hot saturated salt solution in a separatory funnel. The salt-water-insoluble residue was caught on a hard filter paper, and the salt water from the repeated salt-water extractions of the fat was used to wash the filter. Finally, the protein residue was scraped from the filter paper and mixed

in a jar with the extracted fat. Enough saturated salt solution was then added to equal the water content of the original butter, and the mixture was stirred, hardened, and stored.

Both these samples, the washed and the extracted, were prepared to demonstrate the possibilities that may occur when butter is overworked, and also to show the effect of the absence of salt-water-soluble compounds on the keeping qualities of butter. The only comment made on either of these samples by the scorers, was that the butter was "tallowy." This was of course due to handling.

No fishy flavor was developed in the samples of butter used for tables 7 and 10, despite the fact that salt is a contributing factor in the development of fishy flavor in butter during storage. As lecithin is soluble in salt solution, the reason for washing and extracting the butter samples was to remove this phosphorus compound and note whether fishy flavor developed in the samples treated in this manner. The samples included in table 10 were used to ascertain whether butter samples of varying salt content would develop fishy flavor more quickly in one salt concentration than in another. These samples were used also to test the influence of the varying salt concentrations on the soluble phosphorus compounds in the butter. No flavor which in any way resembled fishy flavor was detected in any of the samples, but table 10 shows the influence of the various salt concentrations on the soluble phosphorus compounds.

It is the author's opinion, however, that fishy flavor in butter is caused by the decomposition or partial decomposition of the lecithin before churning, and that through the solvent agency of the salt solution the products of decomposition are further broken down in storage to trimethylamine. Trimethylamine may in turn be broken down, or it may be completely adsorbed by some other compound. This latter theory is advanced from the fact that fishy flavor is transitory in some butter.

As evidence of the breaking-down of lecithin in butter during storage, it is only necessary to compare the soluble organic phosphorus content of the butter in table 1 with the soluble organic phosphorus content of the same butter analyzed fifteen months later as shown in table 2. The long period of storage reduced the soluble organic phosphorus almost entirely to the inorganic form in all the samples except 1 and 7, which had a pure lactic acid culture added. Samples 1 and 7 held their soluble organic phosphorus during storage, and there was no decomposition of the organic

phosphorus which became soluble during storage. The lactic-acid bacteria seem to protect the soluble organic phosphorus from decomposition.

Lecithin is soluble in sodium chloride solution, and it is claimed that fishy flavor in butter is caused by the breaking-down of this compound while in solution with salt. The handling of the milk and cream before churning influences the solubility of the lecithin, and its decomposition, both before and after churning, is clearly shown by the records in tables 1 and 2. Its decomposition in butter during storage necessarily follows, as the records show also. Lewkowitsch (1914:802) says, in referring to the lecithin content of butter: "Lecithin has been stated by various observers to occur in butter fat to the extent of 0.017 or even 0.15 to 0.17 per cent (calculated from phosphoric acid). Wrampelmeyer stated 0.007 to 0.033 per cent of lecithin. Jaeckle, however, showed that butter fat contains no compound of phosphorus." These results seem to supply additional proof that lecithin is a variable compound in butter, and give emphasis to the author's conclusions that the methods of handling the milk and cream before churning determine the quantity of lecithin in the resulting butter. Also, the rate at which the lecithin is decomposed during storage is determined by the condition and the handling of the milk and cream before churning. However, the rôle played by *Bacterium lactis acidi* in protecting the soluble organic phosphorus from decomposition is not clearly understood. That some organisms have a specific action on phosphorus compounds has been observed, and a summary of the investigation of this subject is contained herein.

Butter from cream portion	Per cent of P_2O_5				
	NaCl extract, inorganic	NaCl extract, soluble	HCl extract of protein	Protein residue after extraction	Butter-fat residue
1	0107	0153	0051	0120	0022
2	0179	0183	0053	.0163	None
3	0145	0147	0046	0086	Trace
4	0096	0107	0061	0163	Trace
5	0189	.0204	0038	0089	Trace
6	0148	.0158	0053	.0115	Trace
7	.0087	0148	0059	.0091	.0030

Since it may be of interest to some readers to know what amounts of phosphorus were extracted separately by the various extracting agents, table 2 is given in detail on the opposite page.

BACTERIOLOGICAL INVESTIGATION AS TO THE CAUSE OF FISHY FLAVOR IN BUTTER

Since butter contains lecithin — a mononitrogenous monophosphatid — which on decomposition yields glycerophosphoric acid and choline,— the latter further decomposing to methylamine, ammonia, carbon dioxide, and methane,— it can naturally be inferred that the decomposition products of choline are the cause of the fishy flavor found in some butter. Trimethylamine, which tastes and smells like decomposed fish and which is a decomposition product of choline, is believed to cause fishy flavor in butter. And, since both fishy odor and fishy flavor have been produced in butter when the cream from which the butter was made was inoculated, it can only be assumed that the phosphorus compound which decomposes to trimethylamine is broken down or used as pabulum by the bacteria. The bacterium used in the author's experiment was the one isolated by Hammer (1917) from a can of fishy-flavored milk and named *Bacterium ichthyosmius*.

PLAN OF THE EXPERIMENT

Cream containing 30 per cent of butterfat was treated in the following ways:

Portion D: 750 cubic centimeters of sweet cream was pasteurized at 63° C. for thirty minutes, cooled to 9° C., inoculated with 1 cubic centimeter of an aqueous solution of *Bacterium ich'hyosmius*, and churned at once.

After churning, the butter in this case and in all the following treatments was divided, one-half being salted and the other half left unsalted. A check sample (uninoculated and salted) was made also, and all three samples were stored at −10° C.

Portion E: Sweet raw cream was inoculated in the same way as was portion D, incubated at 37° C. for three hours, cooled to 15° C., and churned.

Portion K: Sweet cream was inoculated, and was then incubated at 37° C. for three hours. At the end of that period the acidity was neutralized to phenolpthalein with sodium hydroxide, and the sample was cooled to 15.5° C. and then churned.

Portion N: Cream was inoculated, incubated, and neutralized as was portion K. After neutralizing, one ounce of liquid starter was added, and the mixture was allowed to stand at 15.5° C. for three hours and then churned.

Portion R: Cream was inoculated, one ounce of starter was added, and the cream was allowed to stand at room temperature for three hours to ripen. It was then neutralized and churned.

Portion X: Cream was inoculated, incubated at 37° C. for three hours, and cooled to 15.5 C., and one ounce of starter was added. After three hours the cream was churned.

Each portion of cream was thus represented by an unsalted sample and a salted sample of butter inoculated with *Bact. ichthyosmius*; and a check sample (salted) which was not inoculated. These were all stored at -10° C. Every two weeks during a period of eight months, a count was taken of the bacteria in both the inoculated samples from each portion. All three samples from each portion were scored frequently for quality (flavor).

RESULTS

None of the check samples (uninoculated) were scored as fishy. None of the unsalted samples (inoculated) were scored as fishy. The salted sample from portion D (inoculated), made from fresh cream which was pasteurized and then churned at once, was not scored as fishy by any of the four judges. The bacteria count decreased rapidly both in the salted and in the unsalted sample of portion D.

Samples from portion E were not scored as fishy by the judges. The bacteria count on the salted inoculated sample was 120,000,000 at the time when it was churned, and at the end of six months the count was 460,000. The unsalted sample had a count of only a few bacteria at the end of four months.

The score for portion K was as follows:

Judge	Unsalted sample	Salted sample
No. 1	No comment	Metallic
No. 2	No comment	No comment
No. 3	No comment	Fishy
No. 4	No comment	Fishy

The only difference between the treatment of the cream in this portion and that in portion E was in the neutralization of the cream after incubation.

In portion N there was no comment on the quality of the sample of unsalted butter. The salted inoculated sample was accidentally destroyed at the beginning of the fourth month in storage. The writer, however, had scored the sample as fishy a short time before it was destroyed.

Portion R scored as follows:

Judge	Unsalted sample	Salted sample
No. 1	No comment	Fishy
No. 2	No comment	Oily
No. 3	No comment	Fishy
No. 4	No comment	Fishy

After four months in storage the salted inoculated sample of this portion had a strong fishy odor. At the end of seven months this odor had to some extent disappeared.

The samples from portion X scored as follows:

Judge	Unsalted sample	Salted sample
No. 1	No comment	Metallic
No. 2	No comment	Metallic
No. 3	No comment	Tallowy
No. 4	No comment	Fishy

The bacteria in the salted sample of portion X numbered several millions even after the sample had been in storage for some months.

In the samples of butter just described, fishy flavor was produced by inoculating the cream with *Bacterium ichthoysmius*. The handling of the cream before churning affected the growth of the bacteria differently in every portion. The sweet-cream butter from portion D decreased in its bacteria count very rapidly, and retained a good flavor after being stored for eight months. Portion D compares fairly closely with portion 6 of the earlier experiments as to the way in which it was treated before

churning. The sample from portion 6 retained a large proportion of its total phosphorus, and the soluble organic phosphorus suffered little decomposition, if any. The butter from portion E may be compared with that from portion 2 of the earlier experiments. The total phosphorus content in sample 2 was very high and the amount of soluble organic phosphorus was large. The samples that were scored as fishy in these experiments (from portions K, R, and X) underwent treatment similar to that of sample 4 in table 1. Sample 4 showed a very small amount of organic phosphorus in the soluble form, and it may be inferred that some of its soluble organic phosphorus had been decomposed. All three samples (K, R, and X) prove that where there is a loss of soluble organic phosphorus, fishy flavor develops in the butter. Sample 4 in table 1 also developed a fishy flavor in storage.

Since it seemed necessary to identify the trimethylamine directly, a sample of butter which had been scored as fishy was selected and the trimethylamine was extracted and identified. The method used was as follows: 100 grams of fishy butter was extracted in a separatory funnel with several portions (about 50 cubic centimeters each) of hot water. The washings were separated from the fat and placed in a liter flask. About 25 cubic centimeters of 1.1 caustic potash solution was added to the contents of the flask, the flask was attached to a condenser, and the solution was heated. The distillate was caught in about 50 cubic centimeters of N/10 sulfuric acid solution. The distillation was continued until the volume of the distillate measured about 200 cubic centimeters. The distillate was then evaporated, on a water bath, to dryness. The residue was taken up with a small quantity of 95-per-cent alcohol and again evaporated to dryness. Dehydrated alcohol was then added to the residue, and the extractions were passed through a filter paper into a clean evaporating dish. Several extractions with alcohol were made, after which the new filtrate was evaporated to dryness on a water bath in a covered hood. The new residue, consisting of trimethylamine sulfate, was dissolved in a small quantity of warm water and the contents of the evaporating dish were washed into a 300-cubic-centimeter Erlenmeyer flask. About 5 cubic centimeters of 1:1 caustic potash solution was added to the contents of the flask, and the whole was distilled into 50 cubic centimeters of N/50 hydrochloric acid. A few drops of the distillate were carefully mixed on a glass slide with a solution of platinic chloride,

and orange-colored crystals, octahedral in shape, were produced. Blank checks on the reagents and the water used showed no evidence of contamination with ammonium or potassium, both of which yield crystals of this type. To check the results, a solution of trimethylamine hydrochloride was prepared for comparison, and this gave results identical to those of the trimethylamine salt obtained from the fishy-flavored butter.

As the experimental data show, when cream is handled in certain ways the organic phosphorus compounds which are soluble in salt solution are decomposed more or less before churning or soon after the resulting butter is placed in storage. The organic phosphorus compound lecithin, which is soluble in sodium chloride solution, represents almost entirely, if not entirely, the soluble phosphorus in the organic form as shown in table 1. This soluble organic phosphorus gradually suffers decomposition, as may be seen in table 2. With the exception of two cases, samples 1 and 7, all the samples that had a significant amount of soluble organic phosphorus suffered decomposition of this component during storage; and in the experiment with *Bacterium ichthyosmius*, the butter which, from the method of handling the cream before churning, could be compared to samples 1 and 7, did not develop the fishy flavor. The butter that did decrease in its soluble organic phosphorus content as shown in tables 1 and 2, may be compared to those samples that became fishy in the inoculation experiment.

This publication deals only with the phosphorus in butter, in its various compounds. However, it is an appreciated fact that there are compounds of other salts, and of calcium especially, which have a marked influence on the keeping qualities of butter. Lactic acid also must play no small part in bringing about chemical changes in butter. Further studies are being made on the keeping qualities of butter as affected by calcium compounds and lactic acid.

SUMMARY

For the experiments described in the foregoing pages, butter was made from cream treated in the following ways: sweet cream ripened with starter; sweet cream churned without starter; lactic acid added to cream and the mixture pasteurized; raw cream self-ripened; lactic acid added to cream and churning begun at once; sweet cream pasteurized and then churned immediately; pasteurized sweet cream ripened with starter.

All the methods of handling had some influence on the phosphorus compounds in the cream and subsequently on the phosphorus compounds in the stored butter. Pasteurization had the most decided influence. When cream containing acid was pasteurized, an appreciable amount of phosphorus was rendered soluble and lost in the buttermilk and the wash waters. Much of this phosphorus evidently came from the insoluble protein residue. Pasteurized sweet cream suffered but little phosphorus loss except in the protein residue. More phosphorus was lost when pasteurized sweet cream was subsequently ripened with starter. In the unpasteurized samples, sweet-raw-cream butter retained the largest amount of phosphorus, butter made from raw cream ripened without starter was next, while butter made with starter ranked third.

After fifteen months the samples were again analyzed, and the analyses showed that the phosphorus in the organic compounds had broken down to the inorganic form. Exceptions to this were in the butter made from raw cream ripened with starter, and in the butter made from pasteurized sweet cream subsequently ripened with starter. With the exception of these two, all the samples increased in the phosphorus content of the protein residue. All samples, without exception, increased in soluble inorganic phosphorus during storage. The organic phosphorus compounds in the unsalted samples were slower to break down than were the organic phosphorus compounds in the corresponding salted samples.

There seems to be plenty of evidence that an alcohol-soluble protein containing phosphorus exists in butter and is closely related to casein.

From the results obtained with the samples of butter containing varying amounts of sodium chloride, it can be inferred that salt has an accelerating action on the solubility of insoluble organic phosphorus compounds.

About two-thirds of the total phosphorus of the cream is retained in the buttermilk, and the remaining one-third is shared by the wash waters, the salt exudates, and the butter. The butter finally retains about one-quarter of the phosphorus originally present in the cream.

After fifteen months in storage, all the phosphorus compounds in the fat could be extracted by shaking in a separatory funnel with half-saturated sodium chloride solution.[6] A 0.2-per-cent solution of hydrochloric acid was found necessary to extract the soluble phosphorus in the protein residue.

[6] Extraction with the aid of centrifugation was not tried on the samples used for table 1.

The substance that produces fishy flavor in butter, is undoubtedly preformed in the cream by the breaking-down of the lecithin. It may be assumed that through the solvent action of salt water and lactic acid, trimethylamine (the constituent giving fishy flavor) is formed from one of these broken-down fractions.

CONCLUSIONS

1. In churning, about one-fourth of the total phosphorus of the cream is retained in the butter made therefrom. The remaining three-fourths is lost in the buttermilk, wash waters, and exudates during the salting process.
2. The methods of treatment of milk and cream before churning have an influence on the amount and the form of phosphorus retained in the butter.
3. In storage the soluble organic phosphorus compounds break down, giving inorganic phosphorus compounds.
4. The methods of treatment of milk and cream before churning determine how soon after storage organic phosphorus compounds will assume the inorganic form.
5. Salt in butter has a marked effect in bringing about protein decomposition during storage, even at a temperature of $-10°$ C.
6. The new protein of milk which is soluble in alcohol exists also in butter.
7. Under certain conditions, bacteria are the controlling factors in bringing about chemical changes in the phosphorus compounds of butter.
8. The breaking-down of lecithin and the forming of trimethylamine is the cause of fishy flavor in butter.
9. When fishy flavor develops in butter there is always an appreciable loss of soluble organic phosphorus.

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THE LECITHIN CONTENT OF BUTTER AND ITS POSSIBLE RELATIONSHIP TO THE FISHY FLAVOR

GEORGE CORNELL SUPPLEE

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CONTENTS

THE LECITHIN CONTENT OF BUTTER AND ITS POSSIBLE RELATIONSHIP TO THE FISHY FLAVOR

THE LECITHIN CONTENT OF BUTTER AND ITS POSSIBLE RELATIONSHIP TO THE FISHY FLAVOR[1]

George Cornell Supplee

The commercial value of butter is based to a great extent on its quality, which in turn is determined by its flavor. The commercial grading of butter on this basis, and the recognition of certain characteristic defects, have resulted in the establishment of certain terms more or less descriptive of the flavors found. Among the terms commonly applied to the flavors in butter are such words as *metallic, fishy, oily, rancid, tallowy*. Since the presence of any of these flavors carries with it a reduction in commercial value of the butter, considerable effort has been made to determine their causes and prevent their development. Unfortunately most of these efforts have not met with a high degree of success. This may be ascribed to several reasons, among which are the following: lack of positive identification of the same flavor by different investigators; lack of adequate chemical methods for the isolation and measurement of the small amount of substance capable of producing the flavor; and lack of cooperation between the chemist, the bacteriologist, and the experienced butter judge.

Fishiness in butter, with which this investigation is primarily concerned, is usually described as a flavor resembling that of salmon or mackerel, altho the names of other varieties of fish are occasionally used to describe the flavor more explicitly. While the typical fishy flavor in butter is readily recognized by experts, it is often accompanied by a more or less oily condition which tends to create differences of opinion as to its exact nature. But if the opinion of butter judges of long experience is to be considered as trustworthy, it may be said that the true fishy flavor is entirely distinct from the oily flavor even tho the oily condition may precede or accompany it.

PREVIOUS INVESTIGATIONS

The earlier investigations bearing on fishiness in dairy products have been largely confined to milk and butter. One instance is recorded, however, in which this condition was observed and studied in evaporated milk.

[1] Also presented to the Faculty of the Graduate School of Cornell University, December, 1918, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

Harding, Rogers, and Smith (1900)[2] report the fishy flavor in a sample of milk brought to the New York State Agricultural Experiment Station at Geneva in 1900. The source was traced to a single animal in the herd, but investigation failed to locate any pathological condition or any irregularity in the feeding which might cause the trouble. Attempts to reproduce the flavor by inoculating milk with bacteria isolated from this cow's udder also failed. The same authors mention also an instance brought to their attention by W. E. Griffith, in which a peculiar flavor developed in June butter after storage at 18° to 22° F. This flavor was described by butter experts as fishy.

Piffard (1901) discusses the fishy flavor in dairy products, and suggests the possible relationship between certain algae found in stagnant water, and fishiness in milk and butter. His theory is supported by the fact that the flavor is often produced in water by the growth of algae and diatoms, and he believes, therefore, that cows having access to such water may transmit the condition to milk. Referring to the flavor in butter, he considers the idea that salt may be responsible and mentions the ability of salt to absorb flavors and odors of materials stored near it.

Harrison (1902), discussing butter defects at about the same time, states that the characteristic off-flavors of butter — fishy butter being specifically mentioned — are caused by the growth of undesirable bacteria in the cream.

O'Callaghan (1902) published certain observations on fishiness in Australian butter. He states that he has found this condition in butter only two hours old. From his investigations he concludes that *Oïdium lactis* is the causal agent. Later (O'Callaghan, 1908) he elaborated on his former views, concluding that *Oïdium lactis* associated with the lactic-acid bacteria in cream will usually produce a fishy flavor in the butter. He mentions the presence of the defect in unsalted butter, and recommends the improvement of sanitary conditions in the creameries, and pasteurization, as a remedy. His conclusions have not been confirmed by other investigators.

Rogers (1909), after a rather exhaustive study of the occurrence and cause of fishy butter, confirms many observations commonly noted in connection with this trouble but is unable to confirm the observations of O'Callaghan. He also seemingly eliminates the theory that trimethyl-

[2] Dates in parenthesis refer to *Bibliography*, page 150.

amine is directly responsible for the flavor. After studying the effect of high-acid cream, overworking, and the consequent increased oxygen content of the butter, and by conducting bacteriological investigations, he concludes that high-acid cream is essential to bring about the condition, altho he points out that not all butter made from such cream develops the fishy flavor. In this respect he states (page 20 of reference cited) that "fishy flavor may be produced with reasonable certainty by overworking the butter made from sour cream." From his viewpoint the probability that microorganisms are the cause falls into disfavor by the advancement of the opinion that "fishy flavor is caused by a slow, spontaneous, chemical change to which acid is essential and which is favored by the presence of small amounts of oxygen" (page 20 of reference). More recently the same author (Rogers, 1914, a and b) points out that fishiness in butter may be preceded by an oily or a metallic flavor, and reiterates his views that the evidence is against the theory that the fishy condition is of a bacterial nature. He also states (1914 b) that "fishy flavor is said to occur rarely or not at all in unsalted butter and it is possible that the salt furnishes certain conditions which are essential to the development of the flavor."

Reakes, Cuddie, and Reid (1912) find no significant differences in the bacterial flora of fishy and of high-grade butter, and, in agreement with Rogers, state that "the development of fishy flavour in butter arises as a result of a chemical change inducing a splitting-up of some of the constituents into compounds possessing this peculiar character of smell and taste, the factors responsible for such change being apparently a degree of high acidity of the cream and overworking."

Hunziker (1916) states that high pasteurization temperatures (185° F.) when used on sour cream tend to produce a very poor quality of butter, which often has a disagreeable oily taste suggestive of fishiness. He points out that this is particularly true when cows are on green pasture and the butterfat contains a rather high percentage of olein, which may be oxidized with relative ease in the presence of high temperatures and high acid.

Hammer (1917) reports that he found a can of evaporated milk which possessed a marked fishy flavor and odor and from which he was able to isolate an organism heretofore undescribed. He gives to this organism the name *Bacterium ichthyosmius*, which was suggested by Dr. A. W.

Dox. The description of the organism seems to indicate that it is closely allied to the Proteus group. By inoculation experiments Hammer was able to reproduce the flavor in milk and cream under both aerobic and anaerobic conditions. He noted that the intensity of the odor was increased by the addition of alkali to the milk after the incubation period. He was unable, however, to produce fishiness in butter by direct inoculation or by inoculating the cream before churning. Bacteria counts at various intervals during the storage period showed an immediate decrease in numbers in salted butter, and an increase during the first few days in unsalted butter followed by a pronounced decrease.

Washburn and Dahlberg (1918), while studying the influence of salt on storage butter, found that salted butter was more likely to turn fishy in storage than was unsalted butter, and furthermore that there appeared to be a tendency toward a progressive development of the flavor thru metallic to oily and finally to fishy.

LECITHIN DECOMPOSITION IN BUTTER AS A POSSIBLE CAUSE OF THE FISHY FLAVOR

CHEMICAL CONSTITUTION, PROPERTIES, AND DISTRIBUTION OF LECITHIN

Lecithin, which stands in close relation to the fats, belongs to a more or less definite group of substances known as phosphatides, or phosphorized fats. These bodies appear to be a group of esters containing nitrogen, phosphoric acid, and fatty-acid radicals. Lecithin, which is the best known of the phosphatides, contains two fatty-acid radicals and the nitrogenous base choline, combined with glycerophosphoric acid. According to the kind of fatty acid present in the molecule, it is possible to have various types of lecithin, such as stearyl, palmityl, and oleyl. A number of investigators seem to agree that every true lecithin contains at least one oleic-acid radical. There seems to be uncertainty as to whether choline is the only base present in lecithin. MacLean (1909) was able to get only 42 per cent of the theoretical amount from lecithin isolated from heart muscle, and 65 per cent from lecithin of egg yolk. Other investigators have found the same to hold true of lecithin from different sources.

Lecithin has certain properties in common with the fats, particularly with respect to its solvents. It differs, however, by being less soluble

in ether and more soluble in alcohol. It is precipitated from alcoholic solution by acetone; in water it swells to a colloidal mass which on microscopic examination appears as oily drops and threads. It saponifies with alkalies and baryta water, yielding the corresponding soaps, salts of glycerophosphoric acid, and choline. Hammarsten and Hedin (1915) state that it is slowly decomposed by dilute acids and enzymes (lipase). Barger (1914) states that *Bacterium prodigiosus* produces trimethylamine from choline and lecithin; he also cites references to show that lecithin is decomposed during putrefaction, yielding fatty acids, glycerophosphoric acid, choline, and ultimately trimethylamine. Hasebroek (1888) claims that methylamine, ammonia, methane, and carbon dioxide may be finally produced from choline during putrefaction. On being heated with strong caustic soda or potash, lecithin yields trimethylamine, which has a distinct fishy odor, this being one of the characteristic qualitative tests for it. Leathes (1913), in citing the work of various investigators, seems to think that lecithin is rather unstable. He thinks this property is due to the unsaturated oleic-acid radical contained, and offers this as the reason why the substance gives Pettenkofer's reaction. The work of Long (1908), however, seems to indicate that lecithin is more stable than has been generally believed. Koch (1902–03) has shown that various salts will cause lecithin to precipitate as a gelatinous mass, and that acids, if sufficiently dissociated (0.005 M sulfuric), will accomplish the same thing.

Lecithin seems to be widely found in nature, being present in many plant cells and animal fluids. It is particularly abundant in the brain, the nerve tissue, and the yolk of egg. It is also reported as existing in blood corpuscles, blood plasma, lymph, milk, and bile. Since the methods used for the quantitative estimation of lecithin depend on the determination of phosphorus in alcoholic or alcohol and ether extracts, it is doubtful whether the figures given are absolutely correct due to the fact that other phosphatides are extracted and also because the empirical formula used in the calculation may be inaccurate for the particular lecithin involved. Altho there have been conflicting statements as to whether milk contains lecithin, there seems to be sufficient evidence that it does. The results obtained by Nerking and Haensel (1908) are submitted in table 1:

TABLE 1. THE LECITHIN CONTENT OF VARIOUS MILKS
(From Nerking and Haensel)

Kind of milk	Percentage of lecithin		
	Highest	Lowest	Average
Human, 10 samples	0 080	0.024	0 050
Cow's, 17 samples	0 116	0.036	0 063
Ass's, 6 samples	0 039	0 006	0 016
Ewe's, 4 samples	0 167	0 051	0 083
Goat's, 11 samples	0 075	0 036	0 049
Mare's, 8 samples	0 017	0.007	0 011

Glikin (1909), studying the lecithin and iron content of milk, reports 0.0515 per cent lecithin in whole milk, 0.05 per cent in cream, and 0.1329 per cent in human milk. Fetzer (1911), studying the lecithin content of milk under pathological conditions, finds that it is lower in milk from cows suffering with mastitis than in milk from normal cows. He finds also that the lecithin content decreases as the fat decreases. The work of Bordas and De Raczkowski (1902) indicates that the amount of lecithin varies with the lactation period. They find that it is at the maximum at the beginning, and gradually decreases during the remainder of the period. Their observations were from seven cows.

THEORETICAL DISCUSSION

Trimethylamine as a decomposition product of lecithin was brought to the attention of the writer as a possible cause of the fishy flavor in butter about three years ago, when he was working with lecithin isolated from brain tissue. Altho there seem to be no published data concerning trimethylamine in relation to this subject, and Rogers (1909) claims that it can be worked into butter in large amounts without producing the fishy flavor, it is nevertheless believed by many that this substance is in some way responsible. On boiling lecithin isolated from brain tissue and egg yolk with strong caustic soda, the writer has been able to obtain a distinct oily and fishy odor which was asserted by many to be typical of the odor of fishy butter. The only possible source of such an odor in this case was the trimethylamine derived from the lecithin. This result, together with the fact that there seems to be good evidence that lecithin is present in milk, led to the assumption that the substance

may exist also in butter and that by its decomposition it can slowly liberate trimethylamine with the consequent production of the fishy flavor and odor.

Provided that lecithin can be shown to exist in butter, the above assumption is supported by several facts. It is well known that enzymes are capable of bringing about many chemical decompositions which result from the action of acids and alkalies on organic substances. It also appears to be a fact that butter may contain enzymes derived from the udder, and from the action of bacteria in the milk or the cream before it is made into butter, and furthermore that the activity of such enzymes is not entirely stopped at the temperature at which butter is stored. Hammarsten and Hedin (1915) state that lecithin is decomposed by dilute acids and enzymes. The citations of Hasebroek (1888), Barger (1914), and others show that lecithin is decomposed by bacteria yielding choline, which finally yields trimethylamine. It is also a well-known fact that this substance in very small amounts possesses a distinct fishy odor, but in concentrated solution it has a strong ammoniacal odor. Speaking of the former property, Davis (1912), quoting Taylor, states that the "odour [referring to the peculiar fishy odor suggestive of herring brine] is gradually developed by adding lime to a solution of the base, but requires some time to reach its maximum intensity."

In addition to the foregoing facts the writer has observed certain features that may have some bearing on this problem. In inspecting butter used in the Navy, it has been noticed that certain samples of cream evolved a peculiar fishy odor on the addition of alkali used for titration. This phenomenon was first brought to the attention of the writer by A. M. Besemer, and has since been confirmed by a number of men, some of whom have wide reputation as butter judges. Since trimethylamine is a base which is liberated from its acid combinations by alkalies, it is quite possible that the odor mentioned above was due to this substance's having been liberated from its acid combination in the cream. If such were the case, it is conceivable that butter made from such cream might, during storage, give up its trimethylamine thru the action of enzymes. In this connection it has been noted that certain samples of old butter, which were not scored as fishy, when brought into contact with a warm solution of soap powder would give off a strong herring-like odor. This phenomenon might also be explained as in the case of the cream. In addition to these features it has been noted that certain samples of fishy

butter may lose their characteristic flavor after a period of time. This has also been observed by other investigators. It is possible that this characteristic may be explained by the fact that, since trimethylamine is extremely volatile, it may pass off, or that the instability of the acid combination changes so that the conditions are not right for its manifestation. The writer has noted a very strong fishy odor in partially decomposed egg yolk held at refrigerator temperature, which had entirely disappeared two weeks later.

On the basis of the foregoing facts and observations and the evident lack of contradiction of most of them with what is known about fishy butter, the following experimental work was planned with the object of determining the possible relationship of trimethylamine to this flavor. In calling attention to the lecithin, it may be stated that the writer is cognizant of the fact that trimethylamine may be produced from other substances. This material has been chosen as the object of study primarily because there is exact knowledge concerning its cleavage and some of the agencies bringing this condition about.

INVESTIGATIONAL WORK

QUALITATIVE DETERMINATION OF LECITHIN IN BUTTER

The first experimental work undertaken was to demonstrate the presence of lecithin in butter, since there appeared to be no reports on this point in the literature. One hundred grams of melted butter was thoroly mixed with sufficient anhydrous calcium sulfate (about one kilogram) so that the mixture retained its dry powdered form to such an extent that it could be readily sifted between the thumb and the finger. The mixture was transferred to a specially constructed percolator and extracted for 48 hours with 95-per-cent alcohol at 60° C. The alcoholic extract was evaporated down and the residue was treated with a small amount of ether, which took up the fat, the fatty acids, and part of the lecithin. The part insoluble in ether was again taken up with warm alcohol, and what may be termed the *lecithin fraction* was precipitated by thoroly cooling the alcoholic solution. The substance thus obtained precipitated in the form of small, wart-like masses, which clung tenaciously to the sides of the beaker. On this material, which presumably contained a high proportion of lecithin, various observations were made and qualitative tests applied. The following characteristics were noted:

On drying at ordinary temperature and pressure the material appeared as a semi-amorphous and oily substance of a pale, dirty yellow color. It was entirely soluble in alcohol but was partially thrown out of solution by the addition of an excess of ether. The precipitate formed in this manner was finely granular and was white in color. In water it formed a semi-colloidal solution which on microscopic examination appeared as minute oily drops. When the watery suspension was heated, the particles would cohere to form a sticky mass which changed to a distinct brown color. Both the dry substance and the watery suspension, when heated with strong caustic soda, gave off a marked fishy odor resembling sometimes dried herring and sometimes salmon oil. This observation was in the great majority of cases confirmed by a number of colleagues. The fishy odor obtained from the material in this manner seemed to furnish positive evidence that lecithin was present. To further strengthen this belief, Pettenkofer's test with sugar and sulfuric acid was applied to the dry material with positive results. The above observations were confirmed with lecithin extracted from fresh butter, salted and unsalted, and from other miscellaneous samples of normal butter.

Altho the evidence that lecithin exists in butter in detectable quantities seemed conclusive, it was decided to determine, if possible, the presence of choline, which, as already pointed out, is one of the components of the lecithin molecule. This was accomplished by boiling the residue of the first alcoholic extract with baryta water, which removed all fat, fatty acids, and fatty-acid radicals of the lecithin in the form of barium soaps. After the barium soaps were filtered off, the excess barium was removed with carbon dioxide, the barium carbonate filtered off, and the filtrate containing choline and barium glycerophosphate evaporated to a sirupy consistency. This residue was then treated with absolute alcohol, in which choline is soluble but barium glycerophosphate is insoluble. On evaporation of the absolute alcohol a small amount of sirupy substance remained. To this material qualitative tests for choline were applied. The most characteristic of such tests is the periodide test described by Staněk (1905), which is made by adding a small amount of strong iodine solution (153 grams of iodine and 100 grams of potassium iodide in 200 grams of water) to an aqueous solution of choline. A positive test is indicated by the formation of a brown precipitate of choline periodide, which on microscopic examination in the presence of the reagent appears as dark brown refractive and notched prisms or rhomboidal

leaflets. On evaporation of the reagent the crystals lose their shape and appear to liquefy, forming brown, oily droplets which again assume their crystalline structure on the addition of more reagent. On the application of this test to the choline obtained from butter lecithin, it was found that the results conformed in all respects to the descriptions of this periodide. The accompanying plate of photomicrographs (Plate VI) shows the characteristic crystals and oily droplets of the periodide formed by the choline from butter. In addition to this test it was shown that the small amount of choline obtained would give off a slight but distinct fishy odor on being heated with solid caustic soda.

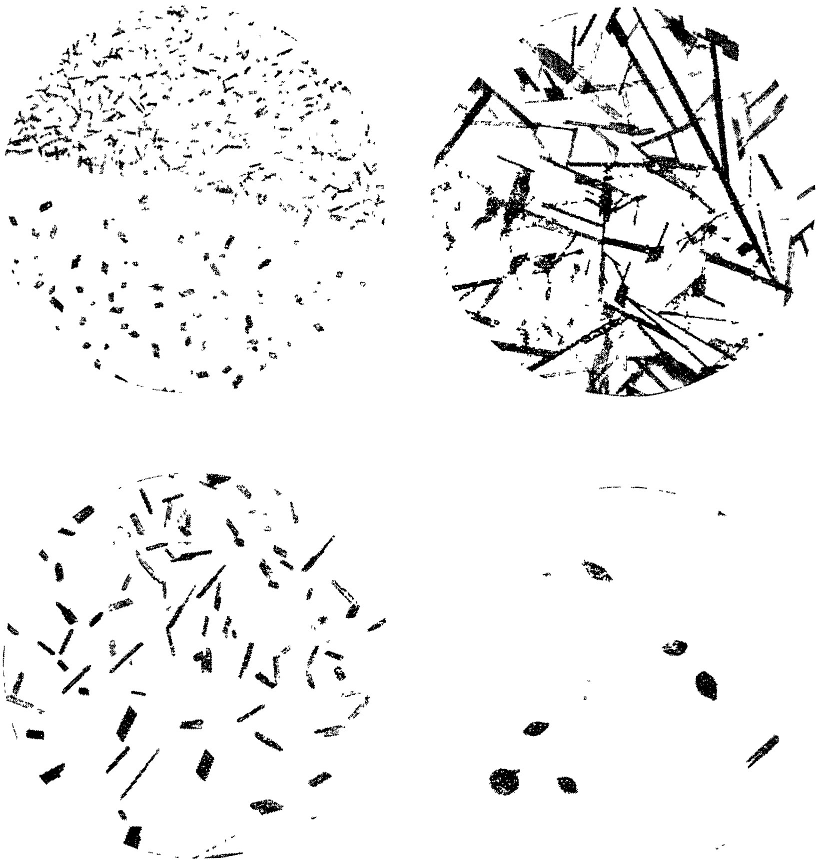
AMOUNT OF LECITHIN IN BUTTER

Since the qualitative tests seemed to leave no room for doubt as to the presence of lecithin in butter, the next step was the quantitative estimation of this substance. In view of the evident difficulty in securing an absolutely pure lecithin free from other phosphatides, the estimations were based on the phosphorus content of extracts and the amount of lecithin calculated according to the formula of the distearyl type. The results of such determinations on various types of butter made from different lots of cream are shown in table 2.

TABLE 2. LECITHIN CONTENT IN VARIOUS BUTTERS*

Sample	Type of cream from which butter was made	Age of butter (days)	P_2O_5 (per cent)	Lecithin, distearyl type (per cent)
1	Raw sweet	6	0 0127	0.0723
2	Pasteurized sweet	6	0 0127	0 0723
3	Raw ripened	6	0.0122	0 0693
4	Pasteurized ripened	6	0 0075	0 0133
5	Raw sweet	48	0 0092	0 0522
6	Pasteurized sweet	48	0 0120	0 0682
7	Raw ripened	48	0 0086	0 0488
8	Pasteurized ripened	48	0.0083	0 0471
9	Raw sweet	72	0 0111	0 0631
10	Pasteurized sweet	72	0 0089	0.0505
11	Raw ripened	72	0 0083	0 0471
12	Pasteurized ripened	72	0 0095	0 0540

* These figures were furnished by J. T. Cusick, chemist for the State Department of Agriculture, located at Cornell University.



CHOLINE PERIODIDE CRYSTALS OBTAINED FROM CHOLINE OF BUTTER LECITHIN
Photomicrographs, × 380

A study of table 2 shows a fairly constant lecithin content in butter from various lots of cream and in different types of butter made from the same lot of cream. There is one feature, however, which is worthy of note, and this is that in most instances there is a tendency toward a lower lecithin content in the ripened-cream butter than in that made from unripened cream. This may be significant in the light of the statement by Hammarsten and Hedin (1915), that lecithin is decomposed by dilute acids and enzymes. This fact applied to these results might indicate that the acidity of the cream slowly decomposed the lecithin, and its decomposition products, particularly the glycerophosphoric acid, were washed out with the buttermilk. If such were the case it would be very easy to account for the lower phosphorus content in sour-cream butter.

TRIMETHYLAMINE SALTS OF THE FATTY ACIDS

It was decided that before an attempt was made to correlate trimethylamine with the fishy flavor of butter, this substance should be prepared in a pure state and those characteristics determined which might have a bearing on this particular problem. Trimethylamine was made by heating 50 grams of ammonium chloride and 440 grams of a 40-per-cent solution of formaldehyde in the autoclave at 122° C. for thirty minutes. Any excess formaldehyde was then expelled and the trimethylamine liberated from its hydrochloride by distilling from an alkaline solution. A 10-per-cent solution was easily obtained at the ordinary temperature and pressure. The trimethylamine thus procured was combined with lactic, butyric, oleic, and stearic acids, and also with the mixed soluble and insoluble fatty acids obtained from butter according to the procedure outlined by Browne (1899). While the properties of these acid addition products seemed to offer an interesting field for study, only such of their characteristics are recorded here as might have a direct relationship to the fishy flavor in butter, namely, their stability, volatility, and behavior in the presence of sodium chloride.

The lactic-acid combination with trimethylamine proved to be a relatively stable oily liquid possessing no characteristic taste other than that shown by many common salts. The odor, especially after the liquid had been standing in a stoppered bottle, seemed to be slightly fishy. Evidence on this point is not conclusive because it is possible that this was due to excess trimethylamine added at the time of neutralization and

EFFECT OF WORKING TRIMETHYLAMINE SALTS OF THE FATTY ACIDS INTO BUTTER

The character of the trimethylamine salts of the fatty acids in pure state seemed to justify the following series of experiments, in which these salts are incorporated into various types of butter for the purpose of determining the possibility of their producing the fishy flavor in the presence of butterfat. In view of the desirability of incorporating the trimethylamine in logical amounts, the following plan was adopted:

The largest quantity of lecithin reported in cow's milk by Nerking and Haensel (1908) was used as the basis of calculation. These authors report 0.116 per cent as the largest amount found in seventeen samples. For the calculations of this experiment, this was assumed to be lecithin of the distearyl type, and it was further assumed to be pure lecithin with the empirical formula assigned to the type named. Granting these assumptions, this amount would yield on complete decomposition the equivalent of 85 parts per million of trimethylamine. This substance alone or in acid combination was therefore added to cream, wash water, or butter on this basis. It is very evident that because of the volatility of some of the materials and because of mechanical loss, none of the samples of butter when completed would contain 85 parts per million of trimethylamine. The method of arriving at the quantity to be added seemed to afford a uniform basis and to approximate in a logical manner the amount of this substance that might be produced in butter. When the fatty acids were used alone they were added in quantities equivalent to the amounts added in the corresponding trimethylamine salts. The addition of the acids was merely for the purpose of checking against the trimethylamine.

In tables 3 to 9 inclusive are shown the comments of various judges on different types of butter containing trimethylamine added as already indicated and incorporated by various means. Because of the great importance of the personal factor in judging butter, an effort was made in all cases to get a number of men familiar with the various flavor defects of the product. In all cases the samples were so labeled that the judges had no knowledge of their contents. They were instructed to comment on the flavor and to work independently of one another, and it is believed that this injunction was carried out. In presenting the results in tabular form the author has intentionally omitted comments having no direct bearing on the fishy flavor.

TABLE 3. EFFECT ON THE FLAVOR OF BUTTER, OF ADDING TRIMETHYLAMINE AND FATTY ACIDS TO RAW SWEET CREAM WITH 0.23 PER CENT ACID AT THE RATE OF 85 PARTS PER MILLION OF THE FORMER

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
AS	Nothing	...	...	...	Oily	Oily	...
A	Nothing	...	Oily	...	...	Oily	...
1 AS	Trimethylamine	Oily	Fishy	...	Fishy	...	Fishy
1 A	Trimethylamine	Fishy	...	...	...	...	...
2 AS	Trimethylamine lactate	...	...	...	...	...	...
2 A	Trimethylamine lactate	Fishy	Oily	Fishy	Fishy	...	...
3 AS	Trimethylamine butyrate	Fishy	Fishy	Fishy	...	...	...
3 A	Trimethylamine butyrate	Fishy	Oily	...	Fishy	...	...
4 AS	Trimethylamine oleate	Fishy	...	...	Fishy	...	...
4 A	Trimethylamine oleate	...	...	...	...	...	...
5 AS	Trimethylamine stearate	Fishy	...	...	...	...	...
5 A	Trimethylamine stearate	Fishy	...	...	...	...	...
6 AS	Trimethylamine and soluble fatty acids	...	...	Fishy	Fishy	...	Fishy
6 A	Trimethylamine and soluble fatty acids	Fishy	Fishy	Oily	...	...	...
7 AS	Trimethylamine and insoluble fatty acids	...	Fishy	Fishy	Fishy	...	Fishy
7 A	Trimethylamine and insoluble fatty acids	...	Oily	...	...	...	Oily
8 AS	Lactic acid	...	...	...	Fishy	...	...
8 A	Lactic acid	Fishy	Oily	...	...	...	...
9 AS	Butyric acid	Fishy	...	...	...	...	...
9 A	Butyric acid	Fishy	...	...	Oily	...	...
10 AS	Oleic acid	...	Fishy	Fishy	Fishy	...	...
10 A	Oleic acid	...	...	...	...	...	...
11 AS	Soluble fatty acids	...	...	...	...	...	...
11 A	Soluble fatty acids	...	...	...	...	...	...
12 AS	Insoluble fatty acids	...	...	...	...	...	...
12 A	Insoluble fatty acids	...	...	...	...	...	...

TABLE 4. EFFECT ON THE FLAVOR OF BUTTER, OF ADDING TRIMETHYLAMINE AND FATTY ACIDS TO RAW SWEET CREAM WITH 0.23 PER CENT ACID AT THE RATE OF 85 PARTS PER MILLION AND THEN WASHING THE BUTTER IN WATER CONTAINING THE SAME CONCENTRATION OF THE VARIOUS SUBSTANCES

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No 6
BS	Nothing.	...	...	...	Oily	Oily	......
B	Nothing	...	Oily	.....	...	Oily	......
1 BS	Trimethylamine	...	Fishy	.....	Fishy	Oily	Fishy
1 B	Trimethylamine	...	.	Fishy	...	Fishy	.....
2 BS	Trimethylamine lactate	...	Oily	.	Fishy	Oily	Fishy
2 B	Trimethylamine lactate	Fishy	Oily	Fishy	Fishy	......	......
3 BS	Trimethylamine butyrate	Fishy	Oily	Fishy	..	.....	Fishy
3 B	Trimethylamine butyrate	Fishy	....	..	Fishy	...	Fishy
4 BS	Trimethylamine oleate	Fishy	..	.	Fishy	......	...
4 B	Trimethylamine oleate	Fishy	...	....	.	.....	Fishy
5 BS	Trimethylamine stearate	Fishy	Oily	Fishy	Fishy	.....	Fishy
5 B	Trimethylamine stearate	Fishy	.	...	Fishy	....	Fishy
6 BS	Trimethylamine and soluble fatty acids	Fishy	Fishy	.....	Fishy	Oily	Fishy
6 B	Trimethylamine and soluble fatty acids.	Fishy	...	.....	.....	...	Fishy
7 BS	Trimethylamine and insoluble fatty acids	Fishy	Oily	Fishy	Fishy	....	Fishy
7 B	Trimethylamine and insoluble fatty acids	Fishy	..	...	Fishy	....	......
8 BS	Lactic acid	Fishy	....	......	.....	.....	......
8 B	Lactic acid	Oily	...	......	...	....	......
9 BS	Butyric acid	...	...	....	Oily	......	......
9 B	Butyric acid	.....	Fishy	....	Oily	.....	.....
10 BS	Oleic acid	....	Oily	.....	Fishy	....	......
10 B	Oleic acid	...	.....	Fishy	....	....	.....
11 BS	Soluble fatty acids	....	......	....	......	......	......
11 B	Soluble fatty acids	....	...	.....	....	.....	......
12 BS	Insoluble fatty acids	....	.	......	.....	......	....
12 B	Insoluble fatty acids	.	...	......	......	....	......

TABLE 5. EFFECT ON THE FLAVOR OF BUTTER, OF ADDING TRIMETHYLAMINE AND FATTY ACIDS TO RAW SWEET CREAM WITH 0.23 PER CENT ACID AT THE RATE OF 85 PARTS PER MILLION AND THEN WORKING THE SUBSTANCES DIRECTLY INTO THE BUTTER AT THE SAME RATE

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
CS	Nothing	...	...	...	Oily	Oily	...
C	Nothing	...	Oily	...	...	Oily	...
1 CS	Trimethylamine	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
1 C	Trimethylamine	.	Fishy	...	Fishy	Fishy	Fishy
2 CS	Trimethylamine lactate	Fishy	Fishy	Fishy	...	Fishy	Fishy
2 C	Trimethylamine lactate	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
3 CS	Trimethylamine butyrate	Fishy	Fishy	Fishy	Fishy	...	Fishy
3 C	Trimethylamine butyrate	Fishy	Fishy	Fishy	...	Fishy	Fishy
4 CS	Trimethylamine oleate	...	...	Fishy	Fishy	...	...
4 C	Trimethylamine oleate	Fishy	Fishy	Fishy	Fishy	...	...
5 CS	Trimethylamine stearate	Fishy	...	...	Fishy	Fishy	Fishy
5 C	Trimethylamine stearate	Fishy	...	...	Fishy	...	Fishy
6 CS	Trimethylamine and soluble fatty acids	Fishy	...	Fishy	...	Fishy	...
6 C	Trimethylamine and soluble fatty acids	Fishy	...	Fishy	...	Fishy	...
7 CS	Trimethylamine and insoluble fatty acids	Fishy	...	Fishy	Fishy	Fishy	Fishy
7 C	Trimethylamine and insoluble fatty acids	Fishy	...	...	Fishy	Fishy	Fishy
8 CS	Lactic acid	Oily	...	Fishy	...	...	...
8 C	Lactic acid	...	...	...	...	...	...
9 CS	Butyric acid	Fishy	Fishy	...	...	...	...
9 C	Butyric acid	Fishy	...	...	Fishy	...	...
10 CS	Oleic acid	...	...	Fishy	Fishy	...	...
10 C	Oleic acid	...	...	Fishy	Fishy	...	...
11 CS	Soluble fatty acids	...	...	...	...	...	...
11 C	Soluble fatty acids	...	...	...	...	...	...
12 CS	Insoluble fatty acids	Oily	...	...	...	Oily	...
12 C	Insoluble fatty acids	Oily	...	...	...	...	...

TABLE 6. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED RIPENED CREAM WITH 0.32 PER CENT ACID, WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 85 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
DS	Nothing		.	..	.	......	......
D	Nothing................ ...	. .	.	...	. .	. ....	......
1 DS	Trimethylamine	.	Fishy	Fishy	Fishy	Fishy	......
1 D	Trimethylamine	.	. .	Fishy	Fishy	Fishy	......
2 DS	Trimethylamine lactate . .	..	.	.....	. .	......	......
2 D	Trimethylamine lactate.		.	. ...	. .	....	......
3 DS	Trimethylamine butyrate .	Oily	Fishy	..	Oily	Fishy	Fishy
3 D	Trimethylamine butyrate		Fishy	...	Oily	Fishy	......
4 DS	Trimethylamine oleate .. .		.	.....		.....	......
4 D	Trimethylamine oleate		...	..		......	......
5 DS	Trimethylamine stearate		.	.	Fishy	Fishy	......
5 D	Trimethylamine stearate	Oily	.	.	Oily	Fishy	......
6 DS	Trimethylamine and soluble fatty acids		...	Fishy	.	. .	......
6 D	Trimethylamine and soluble fatty acids	. . .	. .	. .		....	......
7 DS	Trimethylamine and insoluble fatty acids.	..	Fishy	...	.	.	......
7 D	Trimethylamine and insoluble fatty acids	... .	Fishy	....		..	......
8 DS	Lactic acid.......	Oily	......	..		. .	......
8 D	Lactic acid	. . .	.....	....		. .	......
9 DS	Butyric acid............. ...	Fishy	Fishy	... ..	.	.	.....
9 D	Butyric acid.	.....	Fishy	.....	....	.	.....
10 DS	Oleic acid......	.....	......	Fishy	.	. .	.. ...
10 D	Oleic acid.	....		Fishy		.	.....
11 DS	Soluble fatty acids		.	. .	..	..	.....
11 D	Soluble fatty acids.	.	..	.	.	...	....
12 DS	Insoluble fatty acids . .	Oily	. . .	.... .	..	Oily	......
12 D	Insoluble fatty acids .	Oily	.	..	..	Oily	.....

TABLE 7. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED SWEET CREAM WITH 0.16 PER CENT ACID, WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 85 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
ES	Nothing	...	...	...	...	...	...
E	Nothing	...	...	...	...	...	...
1 ES	Trimethylamine	Fishy	Fishy	Fishy	Fishy	...	Fishy
1 E	Trimethylamine	Fishy	Fishy	...	...	...	Fishy
2 ES	Trimethylamine lactate	Fishy	Fishy	Fishy	Fishy	...	Fishy
2 E	Trimethylamine lactate	...	Fishy	...	...	...	Fishy
3 ES	Trimethylamine butyrate	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
3 E	Trimethylamine butyrate	...	Fishy	...	...	...	Fishy
4 ES	Trimethylamine oleate	Fishy	Fishy	...	...	...	...
4 E	Trimethylamine oleate	...	Fishy	...	...	...	Fishy
5 ES	Trimethylamine stearate	...	Fishy	...	Fishy	...	Fishy
5 E	Trimethylamine stearate	...	Oily	Fishy	Fishy	Fishy	Fishy
6 ES	Trimethylamine and soluble fatty acids	Fishy	Fishy	Fishy	Fishy	Fishy	Fishy
6 E	Trimethylamine and soluble fatty acids	...	Fishy	Fishy	Fishy	...	...
7 ES	Trimethylamine and insoluble fatty acids	Fishy	Fishy	...	...	Fishy	...
7 E	Trimethylamine and insoluble fatty acids	...	Fishy	...	...	Fishy	...
8 ES	Lactic acid	...	Fishy	...	...	...	...
8 E	Lactic acid	...	Fishy	...	...	...	...
9 ES	Butyric acid	Fishy	...	Fishy	...	...	Fishy
9 E	Butyric acid	Fishy	...	Fishy	Fishy	Fishy	...
10 ES	Oleic acid	...	...	...	Fishy	...	...
10 E	Oleic acid	...	...	...	Fishy	...	...
11 ES	Soluble fatty acids	...	...	...	Fishy	...	...
11 E	Soluble fatty acids	...	...	...	...	Fishy	...
12 ES	Insoluble fatty acids	Oily	...	...	...	...	Oily
12 E	Insoluble fatty acids	Oily	...	...	...	...	...

TABLE 8. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED RIPENED CREAM WITH 0.38 PER CENT ACID, WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 40 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges			
		No. 1	No. 2	No. 3	No. 4
FS	Nothing........................	....	....	....	....
F	Nothing........................	....	....	....	....
1 FS	Trimethylamine........................	Oily	Oily	Fishy	....
1 F	Trimethylamine........................	Oily	Fishy	Oily	....
2 FS	Trimethylamine lactate................	Fishy	....	Fishy	....
2 F	Trimethylamine lactate................	....	Fishy	....	....
3 FS	Trimethylamine butyrate................	Fishy	Fishy	Fishy	Fishy
3 F	Trimethylamine butyrate................	....	Fishy	Fishy	Fishy
4 FS	Trimethylamine oleate................	....	....	....	....
4 F	Trimethylamine oleate................	Oily	....	....	....
5 FS	Trimethylamine stearate................	....	....	....	....
5 F	Trimethylamine stearate................	....	....	....	....
6 FS	Trimethylamine and soluble fatty acids..	....	....	Fishy	....
6 F	Trimethylamine and soluble fatty acids..	Oily	....	....	Fishy
7 FS	Trimethylamine and insoluble fatty acids..	....	....	....	....
7 F	Trimethylamine and insoluble fatty acids..	....	....	....	Fishy
8 FS	Lactic acid........................	....	....	....	....
8 F	Lactic acid........................	....	....	....	....
9 FS	Butyric acid........................	....	....	....	....
9 F	Butyric acid........................	....	....	....	....
10 FS	Oleic acid........................	....	....	....	....
10 F	Oleic acid........................	....	....	....	....

TABLE 9. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED RIPENED CREAM WITH 0.28 PER CENT ACID, OF WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 40 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges			
		No. 1	No. 2	No. 3	No. 4
GS	Nothing	......	......	......	......
G	Nothing	......	......	......	......
1 GS	Trimethylamine	Fishy	Fishy	Fishy	......
1 G	Trimethylamine	......	......	......	......
2 GS	Trimethylamine lactate	Fishy	Fishy	Fishy	......
2 G	Trimethylamine lactate	......	......	......	......
3 GS	Trimethylamine butyrate	Fishy	Fishy	Fishy	......
3 G	Trimethylamine butyrate	......	Fishy	Fishy	Fishy
4 GS	Trimethylamine oleate	Fishy	......	Oily	......
4 G	Trimethylamine oleate	......	......	......	......
5 GS	Trimethylamine stearate	......	......	......	......
5 G	Trimethylamine stearate	......	......	......	......
6 GS	Trimethylamine and soluble fatty acids	......	......	Fishy	......
6 G	Trimethylamine and soluble fatty acids	......	......	Fishy	Fishy
7 GS	Trimethylamine and insoluble fatty acids	......	......	......	......
7 G	Trimethylamine and insoluble fatty acids	......	......	......	......
8 GS	Lactic acid	......	......	......	......
8 G	Lactic acid	......	......	......	......
9 GS	Butyric acid	Oily	......	......	......
9 G	Butyric acid	......	......	......	......
10 GS	Oleic acid	......	......	......	......
10 G	Oleic acid	......	......	......	......

All of the samples of butter represented in tables 3 to 9 inclusive were scored from three to five days after making. They were then placed in storage for different lengths of time and rescored by two or more judges. The results of this examination are shown in table 10. In this table are listed only those samples showing a fishy flavor by unanimous opinion of the persons judging them.

TABLE 10. PRESENCE OF FISHY FLAVOR AFTER STORAGE, IN BUTTER TO WHICH TRIMETHYLAMINE HAD BEEN ADDED AT THE TIME OF MAKING

Sample	Material added	Age (days)	Comments by judges	
			At time of making	After storage
3 CS	Trimethylamine butyrate .	40	Fishy	Fishy
3 DS	Trimethylamine butyrate . .	267	Fishy, oily	Fishy
3 ES	Trimethylamine butyrate .	266	Fishy	Fishy
6 ES	Trimethylamine and soluble fatty acids.	266	Fishy	Fishy
1 FS	Trimethylamine . . .	243	Fishy, oily	Fishy, tallowy
3 FS	Trimethylamine butyrate	243	Fishy	Fishy
3 GS	Trimethylamine butyrate	243	Fishy	Fishy

The results obtained from these experiments bring out some very interesting facts. While there are several conflicting opinions as to the presence of the fishy flavor in any particular sample, it is nevertheless evident that the greatest number of positive comments is found in the samples containing trimethylamine in one form or another. It will also be noticed that usually the greatest uniformity of such comments is found in the samples containing trimethylamine in unstable form. This is particularly true as to the samples to which trimethylamine was added alone, in combination with butyric acid, or in combination with the mixed soluble fatty acids of butter. These results are in harmony with the volatility, the taste, and the odor of the compounds in pure state. The lack, in a few instances, of a majority opinion with regard to the samples containing trimethylamine oleate, trimethylamine stearate, and trimethylamine with the mixed insoluble acids, might be explained on the basis that, since these substances were so extremely unstable, the trimethylamine had nearly all volatilized before the time of scoring. The greater number of positive comments from the salted butter is also worthy of note, and, from what is generally known regarding the occurrence of the fishy flavor in such butter, it might tend to strengthen the trimethylamine theory of this flavor. Another feature found in this series of experiments is that a greater number of fishy-flavored samples were found where the acidity of the cream was the lowest. This condition is in harmony with the chemistry involved, for the reason that butter made from low-acid cream contains less lactic acid when fresh than is

TABLE 9. EFFECT ON THE FLAVOR OF BUTTER MADE FROM PASTEURIZED RIPENED CREAM WITH 0.28 PER CENT ACID, OF WORKING TRIMETHYLAMINE AND FATTY ACIDS DIRECTLY INTO THE BUTTER AT THE RATE OF 40 PARTS PER MILLION

(*S* indicates salted butter)

Sample	Material added	Comments by judges			
		No. 1	No. 2	No. 3	No. 4
GS	Nothing	......	......	......	......
G	Nothing	......	......	......	......
1 GS	Trimethylamine	Fishy	Fishy	Fishy	......
1 G	Trimethylamine	......	......	......	......
2 GS	Trimethylamine lactate	Fishy	Fishy	Fishy	......
2 G	Trimethylamine lactate	......	......	......	......
3 GS	Trimethylamine butyrate	Fishy	Fishy	Fishy	......
3 G	Trimethylamine butyrate	......	Fishy	Fishy	Fishy
4 GS	Trimethylamine oleate	Fishy	......	Oily	......
4 G	Trimethylamine oleate	......	......	......	......
5 GS	Trimethylamine stearate	......	......	......	......
5 G	Trimethylamine stearate	......	......	......	......
6 GS	Trimethylamine and soluble fatty acids	......	......	Fishy	......
6 G	Trimethylamine and soluble fatty acids	......	......	Fishy	Fishy
7 GS	Trimethylamine and insoluble fatty acids	......	......	......	......
7 G	Trimethylamine and insoluble fatty acids	......	......	......	......
8 GS	Lactic acid	......	......	......	......
8 G	Lactic acid	......	......	......	......
9 GS	Butyric acid	Oily	......	......	......
9 G	Butyric acid	......	......	......	......
10 GS	Oleic acid	......	......	......	......
10 G	Oleic acid	......	......	......	......

All of the samples of butter represented in tables 3 to 9 inclusive were scored from three to five days after making. They were then placed in storage for different lengths of time and rescored by two or more judges. The results of this examination are shown in table 10. In this table are listed only those samples showing a fishy flavor by unanimous opinion of the persons judging them.

TABLE 10. PRESENCE OF FISHY FLAVOR AFTER STORAGE, IN BUTTER TO WHICH TRIMETHYLAMINE HAD BEEN ADDED AT THE TIME OF MAKING

Sample	Material added	Age (days)	Comments by judges	
			At time of making	After storage
3 CS	Trimethylamine butyrate	40	Fishy	Fishy
3 DS	Trimethylamine butyrate .	267	Fishy, oily	Fishy
3 ES	Trimethylamine butyrate	266	Fishy	Fishy
6 ES	Trimethylamine and soluble fatty acids.	266	Fishy	Fishy
1 FS	Trimethylamine	243	Fishy, oily	Fishy, tallowy
3 FS	Trimethylamine butyrate . .	243	Fishy	Fishy
3 GS	Trimethylamine butyrate	243	Fishy	Fishy

The results obtained from these experiments bring out some very interesting facts. While there are several conflicting opinions as to the presence of the fishy flavor in any particular sample, it is nevertheless evident that the greatest number of positive comments is found in the samples containing trimethylamine in one form or another. It will also be noticed that usually the greatest uniformity of such comments is found in the samples containing trimethylamine in unstable form. This is particularly true as to the samples to which trimethylamine was added alone, in combination with butyric acid, or in combination with the mixed soluble fatty acids of butter. These results are in harmony with the volatility, the taste, and the odor of the compounds in pure state. The lack, in a few instances, of a majority opinion with regard to the samples containing trimethylamine oleate, trimethylamine stearate, and trimethylamine with the mixed insoluble acids, might be explained on the basis that, since these substances were so extremely unstable, the trimethylamine had nearly all volatilized before the time of scoring. The greater number of positive comments from the salted butter is also worthy of note, and, from what is generally known regarding the occurrence of the fishy flavor in such butter, it might tend to strengthen the trimethylamine theory of this flavor. Another feature found in this series of experiments is that a greater number of fishy-flavored samples were found where the acidity of the cream was the lowest. This condition is in harmony with the chemistry involved, for the reason that butter made from low-acid cream contains less lactic acid when fresh than is

determination. and the end-points of all neutralization processes were compared colorimetrically with the standard neutral color. In table 11 are shown the results obtained by this method from mixtures of known amounts of trimethylamine hydrochloride and ammonium chloride:

TABLE 11. EFFICIENCY OF THE MODIFIED MICRO METHOD FOR ESTIMATING TRIMETHYLAMINE AND AMMONIA

Sample	Actual amount of $(CH_3)_3N$ and NH_3 as hydrochlorides (milligrams)		Amount recovered (milligrams)		Percentage	
	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3
1	6 66	6 66	6 64	6 63	99 70	99 55
2	6 66	6 66	6 51	6.63	97 75	99 55
3	2 30	2 30	2 25	2 278	97 83	99 04
4	1 84	1 84	1 79	1 820	97 28	98 91
5	0 92	0 92	0 885	0 935	96 19	101 63
6	0 92	0 92	0 914	0 935	99 35	101 63
7	0 46	0 46	0.442	0 476	96 09	103 48
8	0 46	0 46	0.476	0 476	103 48	103 48
9	0 276	0 276	0 295	0 323	106 88	117.03
10	0 276	0 276	0.295	0 297	106.88	107 61
11	0 276	0 276	0 295	0 297	106 88	107 61
12	.	0 276	. . .	0 289	......	104 71
13	....	1 84	.	1 820	....	98 91
14		0 92		0 918	....	99 78
15	.	0 46	.	0.459	....	99 78
16	.	0 644		0 646	....	100 31
17	.	0 092	. .	0 105	.	114 13

The results shown in table 11 having justified the reliability of the micro method for measuring small amounts of trimethylamine, a number of fishy-flavored samples of butter were subjected to analysis. The butter was thoroly washed in a separatory funnel five times with equal volumes of water acidified with hydrochloric acid at the rate of 25 cubic centimeters of normal acid to the liter. The wash water was then evaporated to a small volume as quickly as possible, and the trimethylamine and ammonia were determined as outlined above.

In table 12 are shown the trimethylamine and ammonia results obtained from fishy butter appearing in commerce and procured from widely different localities. The ammonia results are shown as a matter of

interest but they probably have no direct bearing on this particular problem. Since the experiments with artificially produced fishy flavor seemed to indicate the importance of acidity, the acid values of the samples are also included. The acidity is expressed as cubic centimeters of N/10 sodium hydroxide used to neutralize 20 grams of butter in boiling alcohol. Trimethylamine and ammonia are expressed in parts per million.

TABLE 12. TRIMETHYLAMINE AND AMMONIA CONTENT AND ACID CONTENT OF MISCELLANEOUS SAMPLES OF FISHY-FLAVORED BUTTER

Sample	Trimethylamine (parts per million)	Ammonia (parts per million)	Acid value
1	30 4	11 2	3 8
2	35 4	14 4	5 7
3	28 8	15 2	5 5
4	27 3	26 1	5 4
5	14 0	18.3	6.8
6	None	11 9	3 5
7	None	20 0	2 7
8	26 0	55 0	3 8
9	No analysis	No analysis	3 8
10	No analysis	No analysis	3 0
11	No analysis	No analysis	11 0

The data submitted in table 12 are of considerable interest in view of the history of some of the samples. On arriving at the laboratory, all of the samples, with the exception of samples 5 and 11, were scored as fishy by several judges. These two exceptions were samples of butter sent from a distance and were presumably scored as fishy when shipped but could not be so judged when received. It will be noted that in both cases there was a higher acid value than in any of the other samples, and also that the trimethylamine content of sample 5 is low. With these exceptions the acid value appears to be relatively constant, as does the trimethylamine content with the exception of samples 6 and 7, in which no trimethylamine whatever was found. The majority of these results would seem to point to a definite trimethylamine-acid relationship, as referred to elsewhere in this paper. It is to be regretted that in three instances the sample of butter submitted was too small to warrant analysis. The available data, however, point to trimethylamine as one of the causal agents in fishy-flavored butter.

DEVELOPMENT OF FISHY FLAVOR IN EXPERIMENTAL BUTTERS

In order that the development of the fishy flavor might be more carefully studied, three series of experimental butters were made with the object of determining the influence of pasteurization, of acidity developed during ripening of the cream, of adding lactic acid to the cream, of inoculating butter with lactic-acid bacteria, and of salt. The procedure followed in each of these series consisted of making nine different types of butter, salted and unsalted, from the same original lot of cream. The different series were made at intervals of from three to six weeks. The description of each of the different types of butter in each of the series, and the designation of the samples, are shown in table 13:

TABLE 13. DESCRIPTION OF TYPES OF BUTTER MADE TO STUDY THE DEVELOPMENT OF FISHY FLAVOR

Treatment of cream or butter	Name of sample					
	Salted			Unsalted		
	A series	B series	C series	A series	B series	C series
Raw sweet cream	ASRS	BSRS	CSRS	ASR	BSR	CSR
Pasteurized sweet cream	ASHS	BSHS	CSHS	ASH	BSH	CSH
Raw cream ripened with starter	ARRS	BRRS	CRRS	ARR	BRR	CRR
Pasteurized cream ripened with starter	APRS	BPRS	CPRS	APR	BPR	CPR
Raw cream ripened naturally	ARRNS	BRRNS	CRRNS	ARRN	BRRN	CRRN
Raw sweet cream with *Bacterium lactis acidi* worked into butter	ASRBS	BSRBS	CSRBS	ASRB	BSRB	CSRB
Pasteurized cream with *Bacterium lactis acidi* worked into butter	ASHBS	BSHBS	CSHBS	ASHB	BSHB	CSHB
Raw sweet cream acidified with lactic acid	ASRLS	BSRLS	CSRLS	ASRL	BSRL	CSRL
Pasteurized cream acidified with lactic acid	ASHLS	BSHLS	CSHLS	ASHL	BSHL	CSHL

The samples indicated in table 13 were placed in storage at a temperature of 0° F. or lower, and were scored by three or four judges at various intervals. The results of these scorings are given in table 14. Noncharacteristic flavors are purposely omitted from this table.

TABLE 14. COMMENTS OF JUDGES ON THE DIFFERENT TYPES OF EXPERIMENTAL BUTTERS AFTER VARIOUS LENGTHS OF TIME IN STORAGE AT 0° F.

Sample	Acid in cream (per cent)	Days in storage	Comments by judges			
			No. 1	No. 2	No. 3	No. 4
ASR	0.27	45	Fishy	...	...	...
ASRS	0.27	45	Fishy	...	...	...
ASRS	0.27	130	Fishy	...	...	...
ASRS	0.27	285	...	Fishy	Fishy	...
BSR	0.18	45	Oily	...	Oily	...
BSRS	0.18	45	Fishy	...	Oily	...
BSRS	0.18	285	...	...	...	Fishy
CSRS	0.162	45	...	Fishy	...	...
CSRS	0.162	285	...	...	Fishy	Fishy
BSHS	0.16	45	Metallic	...	Metallic	...
CSH	0.144	130	...	Oily	...	...
CSHS	0.144	45	Metallic	...	...	...
ARR	0.68	45	Metallic	Metallic	...	...
ARRS	0.68	45	Metallic	...	Metallic	...
ARRS	0.68	90	...	Metallic	Oily, fishy	...
ARRS	0.68	130	Metallic	Oily	Metallic	...
ARRS	0.68	285	Metallic	Metallic	Fishy	...
BRRS	0.567	45	...	Metallic	...	...
CRRS	0.567	90	...	Metallic	Metallic	...
CRRS	0.567	285	Fishy	Oily	Metallic	Fishy
BPR	0.52	45	...	...	Oily	...
BPR	0.52	130	Metallic	...	...	...
APRS	0.66	130	...	Fishy	Metallic	...
APRS	0.66	285	...	...	...	Fishy
BPRS	0.52	45	...	Metallic	...	...
BPRS	0.52	130	Metallic	...	...	...
BPRS	0.52	285	...	Metallic	...	...
CPRS	0.562	90	Oily	...	Oily	...
ARRNS	0.675	130	...	Oily	Fishy	...
BRRN	0.576	45	...	...	Oily	...
BRRNS	0.576	45	Oily, fishy	...	...	...
BRRNS	0.576	90	Fishy	Fishy	Oily, fishy	...
BRRNS	0.576	285	Fishy	Fishy	Fishy	Oily
CRRNS	0.600	90	Fishy	...	Oily, fishy	...
ASRB	0.27	45	Fishy	...	...	...
ASRBS	0.27	45	Fishy	...	...	...
ASRBS	0.27	130	Fishy	Fishy	...	...
BSRB	0.18	45	...	...	Oily	...
CSRBS	0.162	45	Oily, fishy	Fishy	...	...
CSRBS	0.162	90	...	...	Oily	...
CSRBS	0.162	285	...	Oily	Metallic	...

TABLE 14 (*concluded*)

Sample	Acid in cream (per cent)	Days in storage	Comments by judges			
			No. 1	No 2	No. 3	No. 4
ASHBS	0 189	130	Fishy	Oily	...	.
ASHBS	0 189	285	...	. .	Fishy	Metallic
CSHBS	0 144	45	Metallic	Metallic	Metallic	. . . .
CSHBS	0 144	90	Metallic	...	...	...
ASRLS	0 638	45	Fishy	. . . . .	...	...
ASRLS	0 638	90	...	...	Fishy	. . ..
ASRLS	0 638	130	..	Fishy	Fishy	. ...
ASRLS	0 638	285	Fishy	Fishy	Fishy	Fishy
BSRLS	0 665	45	...	Fishy	...	...
BSRLS	0 665	90	.	Fishy	...	. .
BSRLS	0 665	285	.	Fishy	Fishy	Metallic
CSRLS	0 472	45	. .	Metallic	...	...
CSRLS	0 472	285	...	Metallic	Fishy	Oily
ASHLS	0 690	130	. .	Metallic	Metallic	..
ASHLS	0 690	285	...	Fishy	Fishy	...
BSHLS	0 594	45	Fishy	Oily	...	...
BSHLS	0 594	90	...	Fishy	...	. ..
CSHL	0 504	45	Fishy	...	...	...
CSHLS	0 504	45	Fishy	. .	...	...
CSHLS	0 504	285	.	. .	Fishy	Oily

In considering the results from the different types of experimental butter, it is evident that there is considerable diversity of opinion among the judges as to the presence or the absence of the fishy flavor in certain samples. It is also evident that there is some relationship between the metallic, oily, and fishy flavors, particularly when these flavors are not sufficiently pronounced to be distinctive as was the case in these samples. This would seem to indicate that there are possibly certain fundamental conditions which are common to the development of each of these flavors.

Even tho there is difference of opinion as to the presence of the characteristic flavors, certain conclusions may be drawn from these experiments. Probably one of the most significant is the presence of the fishy or the metallic flavor in the salted butters. Of a total of 105 characteristic comments, 93 are found in the samples containing salt. Another conclusion which may be drawn from the relative agreement of the judges, is that the fishy flavor appears oftener in the butter made from

high-acid cream than in that from low-acid cream, there being little difference whether the acid was developed by the use of starter, by ripening naturally, or by the addition of lactic acid to raw sweet cream.

These findings, compared with the results obtained from pasteurized cream either churned sweet, ripened with starter, or acidified with lactic acid — all of which showed fewer fishy samples than did raw cream — clearly indicate that the fundamental cause of this butter defect is primarily biological, not brought about by a spontaneous chemical change in which such agencies do not play a part. While it is evident that acid plays an important rôle in the development of the fishy flavor, it is equally clear that there are other important contributing factors. Just what these factors are, is unknown. The variable results obtained from the same type of butter in the different series would indicate that the original cream or milk possessed the unknown factors which in the presence of lactic acid determined the development of the flavor. From the fact that pasteurization tends to reduce the occurrence of the fishy flavor, it is quite probable that these agencies are bacterial enzymes which are only partially inactivated by heat; or it may even be possible that certain microorganisms which are incorporated in the butter from the cream, either in a living or in a dead condition, could on autolysis liberate the enzymes capable of supplying the determining factor. It may also be added that pasteurization may kill certain enzymes and not others, the particular ones that are important being among those killed.

These contentions are further supported by the fact that in the butters made from raw sweet cream there is a suggestion of fishiness after the first storage period which is not found after the longer periods, the disappearance or lack of further development of the flavor being due to the absence of the proper acid condition. It is clear that large numbers of *Bacterium lactis acidi* added directly to butter without their usual accompanying by-products are not the cause of any characteristic change in flavor.

VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS

The importance of acidity in the manifestation of the fishy flavor by trimethylamine, and the relatively constant acid value of the miscellaneous samples of fishy butter found on the market, emphasized the importance of studying this factor in the experimental butters described

above. The variation in acid value of the different types of butter in each of the three series is shown in tables 15, 16, and 17. Results are expressed as cubic centimeters of N/10 alkali necessary to neutralize 20 grams of butter in boiling neutral alcohol.

TABLE 15. VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS OF *A* SERIES AFTER VARIOUS STORAGE PERIODS

Sample	Acid value after various storage periods			
	43 days	86 days	128 days	310 days
ASR	8 8	10 5	10 8	13 0
ASRS	7.4	8 0	8 2	10.0
ASH	5.8	8 6	10 0	12 1
ASHS	5 7	5.9	5 7	7 2
ARR	8 2	8 5	9 3	10.3
ARRS	8 7	8 4	8 6	10 3
APR	7.7	7 9	8 2	9.8
APRS	8 1	7.8	8 0	9.6
ARRN	8 9	8 6	9 2	10 5
ARRNS	8 8	8 4	8 7	10.5
ASRB	9 7	10.4	11 2	15 0
ASRBS	7 4	7.7	7 8	9 8
ASHB	5 7	8 6	9 5	14 3
ASHBS	5 8	5 9	5.8	9 7
ASRL	8 9	8 8	8 8	10 3
ASRLS	8 9	8 9	9 0	10 0
ASHL	7 0	7 1	7.2	8 0
ASHLS	7 4	6 5	7 1	8 5

The data presented in tables 15, 16, and 17 show many interesting features, some of which are worthy of discussion in connection with this problem. It may be stated in the beginning that the variations in acid value of the different types of butter point to biological agencies as the cause of those variations. The lower acid value obtained in nearly all instances from salted butter indicates a preservative action by the salt, a function which is well known. The greatest increase in acidity is

shown in the butter made from raw sweet cream. It is interesting to note that very few of the samples were scored as fishy. When such a condition was suggested, it is to be noted that it occurred after the first storage period, when the acid value was lowest.

TABLE 16. VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS OF *B* SERIES AFTER VARIOUS STORAGE PERIODS

Sample	Acid value after various storage periods			
	20 days	88 days	126 days	286 days
BSR	13 9	14 6	15.2	17.5
BSRS	9 7	9 5	10 0	10 6
BSH	7 3	9 0	10 6	13 4
BSHS	6 3	6 5	6 8	7.6
BRR	10 1	10 2	10 8	11.9
BRRS	10 1	10 1	10 4	11.3
BPR	10 1	10 1	10 0	11 2
BPRS	9 8	10 1	9 6	11.0
BRRN	11 3	11.7	12 6	14.3
BRRNS	11 2	11.7	11 8	13.8
BSRB	13 6	13.5	14 3	15 4
BSRBS	10 6	10 8	10 8	12.0
BSHB	8 1	8 4	9 0	9 2
BSHBS	6 8	6 6	6.8	8.0
BSRL	11 5	11 5	11.6	12 9
BSRLS	11 5	11 1	11.6	12 6
BSHL	9 4	9 4	9 5	11 0
BSHLS	9 5	9 6	9 6	10 1

With reference to the samples from pasteurized cream as compared with those from raw sweet cream, it will be noticed that pasteurization has tended to cause a lowering of the acid value but has not entirely prevented its gradual increase. This would be in accord with possibilities already stated regarding bacterial enzymes. The data show also a retarding action exerted by the acid originally in the cream. This is evident in the butter made from both raw and pasteurized cream ripened

with starter, from raw cream ripened naturally, and from both raw and pasteurized cream to which lactic acid has been added. In comparing the results from these samples it will be observed that cream ripened naturally shows the greatest increase in acid value, raw cream ripened

TABLE 17. VARIATION IN ACID VALUE OF EXPERIMENTAL BUTTERS OF *C* SERIES AFTER VARIOUS STORAGE PERIODS

Sample	Acid value after various storage periods			
	6 days	48 days	90 days	272 days
CSR	7.8	10.4	11.0	13.5
CSRS	7.0	7.9	8.0	9.7
CSH	4.4	7.6	11.0	12.0
CSHS	4.4	4.7	4.4	5.2
CRR	7.6	9.3	10.4	12.8
CRRS	7.5	8.2	8.4	10.0
CPR	6.6	7.5	8.9	10.0
CPRS	6.5	7.0	7.0	8.2
CRRN	8.5	9.5	10.0	12.9
CRRNS	8.2	9.0	9.1	11.3
CSRB	7.8	10.2	11.8	13.5
CSRBS	6.9	7.4	7.9	9.0
CSHB	4.4	6.5	7.7	7.1
CSHBS	4.4	4.4	4.4	5.2
CSRL	8.3	8.1	8.0	9.8
CSRLS	8.4	8.5	8.4	9.5
CSHL	5.8	6.0	5.9	6.7
CSHLS	6.0	5.7	5.6	6.3

with starter a little less increase, pasteurized cream ripened with starter a still less increase, and cream to which lactic acid has been added the least increase of any in the group. The low acid value caused by the addition of lactic acid might possibly be explained in one of two ways: either the addition of the acid in pure form has tended to inactivate the enzymes, or the lactic acid retained in the butter has been changed to butyric acid during storage — which is entirely possible by enzymatic

action. If such a change as the latter did take place, a lowering of the acid value would be manifested because of the formation of a weaker acid which probably has resulted from the splitting and condensation of two parts of the stronger lactic acid. The possibility of butyric acid being formed in this way might be supported by the fact that the other samples from high-acid cream showed a lower acid value than those from sweet cream but had a higher value than those to which pure lactic acid was added. Even tho this change did take place, however, it is improbable that it could entirely account for the low value indicated. It is more probable that the lactic acid acts as an inhibiting agent. A study of the tables will show that the increase in acid value of the sour-cream butters seems to be greater when the amount of pure lactic acid is lowest in the cream. In using the phrase "pure lactic acid," reference is made to that which was added and also to that developed by bacteria, it being logical to assume that the greatest amount so developed is found in pasteurized cream ripened with starter and the least amount in the raw cream ripened naturally. The condition mentioned above also supports the theory of devitalized enzymes, altho it is more difficult to explain why approximately the same degree of commercial lactic acid has a more marked effect than the acid produced by bacteria. It would seem that the structure of the particular lactic acids involved produced different results in this respect, or that the other acids produced by the bacteria are less inhibitive than the lactic.

Regardless of what the explanation for the variations may be, the data seem to indicate that there may be a relationship between the acid value and the fishy flavor, not so much by a constant condition as by a proper balance between the progressive development of the acid value and some other contributory cause. The most favorable condition would seem to be a very gradual increase in acid value, and one that would be in proper harmony and relationship to some other important and transient factor. If these views can to any degree serve as a basis of explanation, it is comparatively easy to see how an improper balance of any one of the conditions would determine the presence or the absence of the fishy flavor. It might also be conceivable that the intensity of the true flavor would be in inverse proportion to the degree in which these factors were out of equilibrium. Such a conception could explain the occurrence and the disappearance of the flavor in the same sample of butter at different

times, why the fishy, the metallic, and the oily flavors seem to be closely related, and possibly why trimethylamine can be detected in some fishy butters and not in others.

TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS

The micro method already described was used to ascertain the trimethylamine and ammonia content in the experimental butters after different lengths of time in storage. The results of these determinations are shown in tables 18, 19, and 20. Amounts of the substances are expressed in parts per million.

TABLE 18. TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS IN A SERIES AFTER VARIOUS STORAGE PERIODS

Sample	After 128 days		After 347 days	
	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3
ASR	None	36.0	None	17.6
ASRS	None	17.2	None	8.4
ASH	None	23.3	None	16.6
ASHS	None	15.0	None	6.8
ARR	None	29.2	None	30.8
ARRS	3.1	16.8	9.4	18.2
APR	None	34.0	None	24.4
APRS	None	20.7	None	24.0
ARRN	None	25.3	None	25.0
ARRNS	13.5	22.4	None	6.8
ASRB	None	18.4	None	24.4
ASRBS	None	22.1	None	12.8
ASHB	None	23.1	11.8	10.8
ASRL	None	17.3	15.2	9.4
ASRLS	None	14.2	6.0	10.7
ASHL	None	16.3	None	12.2
ASHLS	None	19.3	None	8.8

The results shown in tables 18, 19, and 20, altho erratic, are of importance as indicating the variations in decomposition in the same and in different lots of cream, and further emphasize the complexity of a problem of this nature. The same general results with respect to enzymatic activity in salted and in unsalted butter from raw, pasteurized, and ripened cream are found here as were found in connection with the acid values of the same butters. Altho the trimethylamine results are somewhat discordant, a tendency is shown for the presence of this substance

to harmonize with the samples scored as fishy, metallic, or oily. Of 21 samples in which trimethylamine was found, 15 were assigned one of the characteristic flavors by one or more of the judges at some time during the storage period. In 5 of the remaining instances, it is to be noted that, while trimethylamine was found in the same type of butter of the same series, its presence did not harmonize with the characteristic flavor in the salted or the unsalted sample. On the other hand, there were 10 samples of different types of butter which were indicated as having a characteristic flavor by one or more of the judges at some time during the storage period, in which trimethylamine could not be detected.

TABLE 19. TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS IN *B* SERIES AFTER 323 DAYS IN STORAGE

Sample	$(CH_3)_3N$	NH_3
BSR	None	35 2
BSRS	None	18.0
BSH	...	......
BSHS	53 0	10 2
BRR	None	32 8
BRRS	8 2	21 6
BPR	10 6	23 8
BPRS	9 4	25 0
BRRN	4 7	27 0
BRRNS	None	32 2
BSRB	35 4	29 4
BSRBS	None	20.0
BSHB	5 9	23 0
BSHBS	None	10 4
BSRL	None	23 0
BSRLS	None	17 0
BSHL	None	7.4
BSHLS	None	11 4

While these results are not absolutely conclusive, there is nevertheless an indication that trimethylamine may be one of the contributing factors in the development of the true fishy flavor. It has been shown that this substance is capable of producing a flavor described by butter judges as fishy, this being particularly true in the presence of butyric acid. Furthermore, it has been shown that trimethylamine may be present in fishy-flavored butter. Therefore it would not appear to be beyond the

realm of possibility that the results shown in this paper point to a definite trimethylamine and acid relationship as being the cause of that flavor in butter which resembles the flavor of herring or mackerel brine, and that non-typical flavors resembling other fish products, or the metallic

TABLE 20. TRIMETHYLAMINE AND AMMONIA CONTENT OF EXPERIMENTAL BUTTERS IN C SERIES AFTER VARIOUS STORAGE PERIODS

Sample	After 90 days		After 310 days	
	$(CH_3)_3N$	NH_3	$(CH_3)_3N$	NH_3
CSR	None	30 2	8 2	33 2
CSRS	None	20 0	None	28 2
CSH	None	32 4	....	....
CSHS	None	19 7	None	14 2
CRR	None	36 3	None	20 6
CRRS	None	31 2	None	36 2
CPR	None	34 7	None	29 2
CPRS	None	33 2	14 0	27 4
CRRN	None	37 0	18 8	31 8
CRRNS	None	27.6	8 2	29 8
CSRB	None	33 3	13 0	33 6
CSRBS	None	23 1	5 8	18 6
CSHB	None	31 6	None	31 6
CSHBS	None	34 0	17 6	15 4
CSRL	None	21 4	None	14 8
CSRLS	None	14.2	None	10 8
CSHL	None	38 7	5 8	20 6
CSHLS	None	19 1	....	....

and the oily flavor, may be due to an unbalancing of this relationship, the occurrence of these flavors being due to factors in which the presence of trimethylamine in detectable amounts is in no way contributory.

BACTERIOLOGICAL STUDIES

In an effort to correlate the preceding observations with the biological aspects of the problem, certain bacteriological studies were carried out. These included a bacterial analysis of fishy- and non-fishy-flavored butters, and inoculations with pure and mixed cultures into choline, lecithin, butterfat, and cream for the purpose of finding, if possible, an organism or a group of organisms which in some way might contribute to the development of the fishy flavor.

Bacterial analysis

Bacteriological examinations of fishy- and of normal-flavored butter from various sources seemed to show no characteristic differences in flora, neither were the quantitative results consistent. Even tho the samples examined did not appear to possess marked differences in flora, cultures of the predominating type were isolated from the fishy samples for the purpose of determining a condition under which they might contribute to the characteristic flavor. The types of bacteria found included a number of acid-producing varieties, both coccus and rod forms. Among the species commonly found were *Micrococcus lactis acidi, Mic. lactis albidus, Bacterium lactis brevis, Bact. aerogenes,* and *Bact. lactis flocculus.*

The bacteria content of certain samples of fishy- and of non-fishy-flavored butter is given in table 21:

TABLE 21. NUMBER OF BACTERIA FOUND IN VARIOUS SAMPLES OF FISHY- AND NON-FISHY-FLAVORED BUTTER

Sample	Character of flavor	Bacteria per gram
1	Strong	1,200,000
2	Fishy	1,400,000
3	Fishy	8,000,000
4	Fishy	21,600,000
5	Oily	30,000,000
6	Fishy	60,000
7	Fishy	135,000
8	Oily	3,900,000
9	Strong	760,000
10	Fishy	23,500
11	Fishy	8,300,000
12	Strong	1,600,000
13	Fishy	340,000
14	Storage	2,600
15	Fishy	390,000
16	Fishy	465,000

Inoculations for the purpose of developing the fishy flavor

The results of previous investigations show that little success has been attained in the attempt to develop the fishy flavor in butter by inoculating the butter itself or by inoculating the cream just prior to churning. If the enzymatic idea as already stated in this paper is to be

upheld, such negative results can be explained by the fact that organisms inoculated into the cream just prior to churning, or into the butter, do not have the opportunity for growth and consequent production of by-products which they would have if allowed to grow in the milk or the cream before it is made into butter. There seems to be good evidence that there is a rapid dying-off of the bacteria in butter after the first few days of storage. Furthermore, it is well known that low storage temperatures do not entirely prevent enzymatic activity. Rogers (1909) shows that, while low temperatures delay the development of the fishy flavor, they do not entirely prevent it. In accordance with these facts it is conceivable that certain enzymes which would be produced by the growth of organisms in the cream, and carried into the butter, would there continue their activity, with the consequent manifestation of certain changes in flavor. Results obtained in the present investigation indicate also the importance of a definite acid relationship. With these factors in mind, the inoculation experiments undertaken in connection with this problem were carried out in a manner that would allow for the manifestation of the possibilities indicated.

Nine organisms, all of which were isolated from samples of fishy butter and *Bacterium ichthyosmius* — which Hammer (1917) found would produce the fishy flavor in milk — were used in these experiments. The same original lot of cream was divided into six parts, and each of these parts was further divided into ten parts, each of which was inoculated with a specific organism. Different methods of handling the six groups of ten inoculations each were carried out in such a way that the effect of acid in conjunction with the specific organism could be determined. Adequate checks were made from uninoculated cream. Pasteurized sweet cream was used as the basis for all inoculations. When the cream was neutralized the acidity was reduced to 0.18 per cent. All samples were made up both salted and unsalted, and were scored after 231 days in storage at a temperature of 0° F. or lower. The results of the experiment as regards salted butter are given in table 22.

It is characteristic of the results of this experiment that none of the samples of unsalted butter showed any of the characteristic flavors and are therefore not included in table 22. It is believed that the results shown in the table clearly confirm the opinion that biological agencies, particularly bacterial enzymes, are responsible to a great degree for the flavors indicated; also, that the fundamental condition necessary for the

TABLE 22. EFFECT ON THE FLAVOR OF SALTED BUTTER, OF INOCULATING CREAM WITH SPECIFIC ORGANISMS UNDER DIFFERENT CONDITIONS

Sample	Treatment of cream	Acidity of cream*		Comments by judges			
		1 (+)	2 (+)	No. 1	No. 2	No. 3	No. 4
1	Raw sweet	...	0.18	...	...	...	...
2	Pasteurized sweet		0.12	...	...	...	...
3	Pasteurized sweet, ripened	...	0.38	...	...	...	...
4	Pasteurized sweet, ripened and neutralized	0.38	0.20	...	...	...	...
5	Pasteurized sweet, acidified with lactic acid...	...	0.54	Fishy	Fishy	Oily	Fishy
6	Pasteurized sweet, acidified with lactic acid and neutralized...	0.54	0.18	...	...	...	...
D BI	Pasteurized sweet, inoculated with specific organisms and churned at once	...	0.12	...	...	...	...
D 100		...	0.13	...	...	...	Metallic
D 23		...	0.13	...	...	...	...
D 12		...	0.13	Tallowy	...	...	Tallowy
D 18		...	0.13	Metallic	...	...	Oily
D 19		...	0.13	...	...	...	...
D 8		...	0.12	...	...	...	Oily
D 11		...	0.13	...	...	...	...
D 21		...	0.13	...	...	...	...
D 10		...	...	...	...	...	...
E BI	Pasteurized sweet, inoculated with specific organisms and held 24 hours before churning	...	0.45	...	...	...	...
E 100		...	0.41	...	...	Fishy	Tallowy
E 23		...	0.41	...	Fishy	Metallic	Oily
E 12		...	0.43	...	...	...	...
E 18		...	0.45	...	...	...	...
E 19		...	0.43	...	...	...	...
E 8		...	0.46	...	...	...	...
E 11		...	0.43	...	Oily	Oily	Fishy
E 21		...	0.43	...	...	...	...
E 10		...	0.39	...	...	...	...
K BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, and neutralized before churning	0.45	0.18	Metallic	...	Fishy	Fishy
K 100		0.41	0.18	...	...	...	...
K 23		0.41	0.18	...	...	...	Oily
K 12		0.43	0.18	...	Butyric	Butyric	...
K 18		0.45	0.18	...	...	...	...
K 19		0.43	0.18	...	...	...	...
K 8		0.46	0.18	...	...	...	...
K 11		0.43	0.18	...	Tallowy	...	...
K 21		0.43	0.18	...	...	...	...
K 10		0.39	0.18	...	...	Fishy	...

*1 (+) = acidity at time of neutralizing.
2 (+) = acidity at time of churning.

TABLE 22 (*concluded*)

Sample	Treatment of cream	Acidity of cream*		Comments by judges			
		1 (+)	2 (+)	No. 1	No. 2	No. 3	No. 4
N BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, neutralized, and ripened	0 45	0 32	.	.	... .	.
N 100		0 41	0 36	.		. ..	
N 23		0 41	0 35	. .		..	.
N 12		0 43	0 37	.		.	. . . .
N 18		0 45	0 38	....		. .	.
N 19		0 43	0 36	.	.	.	...
N 8		0 47	0 33	. .	.		.
N 11		0 43	0 29	. .	...	.	. .
N 21		0 43	0 39	.	. .	...	..... .
N 10		0 39	0 39	.	. .		....
R BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, neutralized, ripened, and again neutralized	0 36	0 18	Fishy	Oily	Fishy	Fishy
R 100		0.26	0 18	. .		......	... ..
R 23		0 38	0 18			...	Oily
R 12		0 31	0 18	Butyric	.	. ..	.
R 18		0 33	0 18	.	.	.. ..	. ..
R 19		0 32	0 18	. .	..	Rancid	.... .
R 8		0 29	0 18	..		. ...	Fishy
R 11		0 30	0 18	.		..	Fishy
R 21		0 32	0 18	. .	. .	.	. .
R 10		0.29	0 18	...	. .	. . .. .	... .
X BI	Pasteurized sweet, inoculated with specific organisms, held 24 hours, and ripened	.....	0 29	Metallic	Metallic	Tallowy	Fishy
X 100		.. .	0 42	. .	.....	......	Oily
X 23		......	0 40	Metallic	Metallic	Fishy	Metallic
X 12		.. ...	0 39	Butyric	Butyric	... .	Strong
X 18		......	0 37	. ..		. ...	.....
X 19		......	0 36		. . .	...	.....
X 8		. ..	0 34	.	.	. . .	.. .
X 11		.....	0 36	..		.	.... .
X 21		.. ..	0 36	. . .	.	. .	. ...
X 10		. ..	0 36		. .	. .	. . .

*1 (+) = acidity at time of neutralizing.
2 (+) = acidity at time of churning.

manifestation of these flavors is greatly enhanced by the growth of the organisms in the cream; and furthermore, that a definite acid condition is essential for the development of these flavors, which are potentially possible from the specific bacteria or enzymes. In this experiment it is appreciated that the results are obtained by an associative action with the organisms in the starter and those surviving pasteurization; this fact, however, does not depreciate the specificity of the particular organisms that were inoculated. In reviewing the data from this experi-

ment, it is interesting to note that the sweet pasteurized cream to which lactic acid had been added and which was uninoculated, developed the fishy flavor. The description of the flavor in the same sample of butter by different judges again calls attention to the fact that there seem to be some conditions common to the fishy, the metallic, and the oily flavor.

The most consistent comments from specific organisms seem to be from cultures BI and 23. The former is *Bact. ichthyosmius*, which was obtained from Hammer; the latter is an organism isolated from raw-ripened-cream butter which developed the fishy flavor after two months and retained it for nearly twenty months.

Butter samples E 23 and X BI were analyzed for trimethylamine and ammonia. None of the former substance was found. Sample X BI showed 35.2 parts per million of ammonia, and sample E 23 showed 17 parts per million.

LONGEVITY OF BACTERIUM ICHTHYOSMIUS IN BUTTER

Preliminary experiments with *Bacterium ichthyosmius* indicated that this organism might produce the fishy flavor in butter. It seemed desirable, therefore, to determine its longevity in butter made from the inoculated cream. Results of the quantitative determinations of the bacteria in salted butter containing this organism are shown in table 23; results are given only for those samples to which a characteristic flavor was assigned.

TABLE 23. BACTERIA CONTENT OF SALTED BUTTER MADE FROM CREAM INOCULATED WITH BACTERIUM ICHTHYOSMIUS AND STORED AT A TEMPERATURE OF 0° F. OR LOWER*

Age of sample (days)	Number of bacteria per gram		
	K BI	R BI	X BI
7	23,400,000	10,400,000	...
21	14,400,000	10,100,000	34,250,000
35	10,450,000	8,300,000	28,000,000
49	8,500,000	6,700,000	17,400,000
63	6,300,000	6,350,000	10,150,000
78	1,800,000	4,000,000	11,500,000
91	1,150,000	1,350,000	11,200,000
105	890,000	....	6,400 000
119	750,000	....	5,400,000
134	.	740,000	....
148	.	355,000	..
162	....	37,500	4,600,000

* These results were furnished by J. T. Cusick.

The decrease in bacteria content of the salted butter containing *Bact. ichthyosmius* shows that, altho this organism may contribute to the development of the fishy flavor in butter, it does not do so by active multiplication in that medium.

FURTHER STUDIES WITH BACTERIUM ICHTHYOSMIUS

The results obtained with *Bacterium ichthyosmius* seemed to warrant a further study of its relationship to the fishy flavor in butter. The following experiment was carried out with the purpose of determining the conditions in butter under which the development of the flavor could be accelerated. Pasteurized sweet cream was inoculated with this organism and held for two days at room temperature. The butter made from this cream was divided into twelve parts, and to each of these parts a different substance was added. The cream at the time of churning contained 0.23 per cent acid. The treatment of this butter, and the time of occurrence of the fishy flavor as determined by two or more judges, are shown in table 24:

TABLE 24. FISHY FLAVOR AS DEVELOPED IN BUTTER WHICH WAS MADE FROM CREAM INOCULATED WITH BACTERIUM ICHTHYOSMIUS AND TO WHICH VARIOUS SUBSTANCES WERE ADDED

Sample	Substance added to butter	Days in storage				
		52	94	136	175	328
BI 1	Nothing	...	Fishy	Fishy	Not scored	
BI 2	Berkfeldt filtrate from milk culture of *Bact. ichthyosmius*	...	...	...	...	...
BI 3	Choline, 0.0118 per cent	Oily	...	...	...	...
BI 4	Calcium caseinate	...	...	...	...	...
BI 5	Lactic acid, 0.117 per cent	Fishy	Fishy	Fishy	Not scored	
BI 6	Lecithin from butter	...	...	...	...	Fishy
BI 7	Lactic acid and choline	Fishy	...	...	...	...
BI 8	*Bact. lactis acidi* starter	...	...	...	...	Slightly fishy
BI 9	Berkfeldt filtrate and caseinate	...	...	...	...	...
BI 10	Berkfeldt filtrate and choline	...	...	...	...	...
BI 11	Berkfeldt filtrate, lactic acid, and choline	...	...	...	...	...
BI 12	Berkfeldt filtrate made alkaline	...	Oily	Fishy	Not scored	

All of the butters indicated in table 24 possessed a very disagreeable flavor and odor when fresh but they seemed to improve in quality during storage. The development of the fishy flavor in certain samples shows some very interesting features. In reviewing the results of this experi-

ment it must be borne in mind that the cream from which they were made contained the products of two days growth of *Bact. ichthyosmius.*

The development of the fishy flavor in the sample to which nothing was added, is therefore significant. The earlier occurrence of the flavor in the sample to which lactic acid was added is significant in that it confirms certain observations already noted. The development of the flavor in the sample containing the alkaline Berkfeldt filtrate seems to be about simultaneous with its development in the sample to which nothing was added. The lack of development of the flavor in the samples to which the filtrate was added alone or in combination with other substances, might appear to be contradictory to the enzymatic idea previously expressed. It is believed, however, that this is more than offset by the other data, which point to the necessity of a definite set of conditions that must be met in order to produce the flavor. Such being the case, the absence of the flavor when the filtrate was added may be explained on the basis that the proper equilibrium had been disturbed. The final occurrence of fishiness in the sample containing lecithin is of importance as indicating that this may be the mother substance of the material causing the flavor. Other scattering results do not merit particular discussion at this time.

The trimethylamine and ammonia content of the samples shown in table 24, and their acid value, are given in table 25:.

TABLE 25. TRIMETHYLAMINE AND AMMONIA CONTENT AND ACID VALUE OF BUTTER SAMPLES WHICH WERE MADE FROM CREAM INOCULATED WITH BACTERIUM ICHTHYOSMIUS AND TO WHICH OTHER SUBSTANCES WERE SUBSEQUENTLY ADDED

Sample	Age of sample (days)	$(CH_3)_3N$ (parts per million)	NH_3 (parts per million)	Acid value
BI 1	136	7 2	20 7	8 7
BI 2	328	9 4	30 2	9.5
BI 3	328	5 8	28 4	8 5
BI 4	328	4 6	26 8	7 8
BI 5	94	4.7	12 7	8 2
BI 6	328	9.4	25 4	8 0
BI 7	328	8 2	24 0	8 9
BI 8	328	4 6	22 4	8.5
BI 9	328	5.8	25 8	.....
BI 10	328	.....	.....	9 2
BI 11	328	.....	.....	9.4
BI 12	136	11 8	17.8	9.3

The relatively constant trimethylamine results shown in table 25 indicate strongly that this substance has been produced in the cream by *Bact. ichthyosmius.*

TRIMETHYLAMINE AND AMMONIA PRODUCTION BY BACTERIUM ICHTHYOSMIUS IN MILK AND CREAM

In order to determine the trimethylamine production by *Bacterium ichthyosmius* in milk and cream, 50-cubic-centimeter quantities of these substances, sterilized, were inoculated with the organism alone and in combination with a lactic-acid starter. The inoculations were held for forty hours at 30° C., and the trimethylamine and ammonia were then determined in 20-cubic-centimeter quantities. The results of these determinations are shown in table 26:

TABLE 26. AMOUNT OF TRIMETHYLAMINE AND AMMONIA PRODUCED IN SKIMMILK AND IN CREAM BY BACTERIUM ICHTHYOSMIUS

Inoculation	Material inoculated	$(CH_3)_3N$ (parts per million)	NH_3 (parts per million)
Bacterium ichthyosmius and starter	Skimmilk	None	84
Bact. ichthyosmius and starter	Cream	204.0	88
Bact. ichthyosmius	Skimmilk	94 4	125
Bact. ichthyosmius	Cream	74 7	78

The results presented in table 26 are of great interest as showing beyond a doubt that the fishy flavor produced in milk and cream by *Bact. ichthyosmius* is due to trimethylamine. This being the case, it is obvious that this substance would be carried into the butter, and there, under proper conditions which have already been pointed out, be responsible for the characteristic flavor in that material. With respect to the production of trimethylamine in cream and in milk by this organism, it is desirable to again call attention to the observations of the author, in which the evolution of a fishy flavor was noted on the addition of alkali to sweet cream.

These results are of further importance in that the cream inoculated with starter and *Bact. ichthyosmius* contained a greater amount of trimethylamine than did the cream inoculated with the organism alone. This indicates that an acid condition is most favorable for this particular

fermentation, which would be in harmony with the idea that lecithin furnishes the source of the trimethylamine produced by the organism. The results are supported also by the fact that lecithin is largely associated with the fat, and that according to Hammarsten and Hedin (1915) lecithin is decomposed by dilute acids. Such being the case, it is readily seen that this fermentation brought about by *Bact. ichthyosmius* would be greatly enhanced by the presence of acid. The presence of trimethylamine in skimmilk inoculated with the organism alone might be explained on the basis that the organism was able to produce this substance from proteins as well as from lecithin. Certain data not included in this paper, however, indicate that there is a certain amount of lecithin present in skimmilk. Just why there is no trimethylamine in skimmilk inoculated with the starter and the organism, is more difficult to explain. It may be that the greater acidity in the skimmilk has inhibited the particular factor responsible for trimethylamine production.

PRODUCTION OF TRIMETHYLAMINE FROM LECITHIN AND CHOLINE BY BACTERIAL ACTION

In order to determine, if possible, whether certain organisms found in milk and in butter were capable of decomposing lecithin or choline into trimethylamine, a series of inoculation experiments were carried out. Lecithin alone in 0.3 per cent concentration, and in the presence of lactic acid and salt, was inoculated with a number of organisms, some of which were obtained from milk, some from fishy butter, and some from decomposed egg yolk which had developed the fishy flavor. The following known species were also used: *Bacterium lactis acidi*, *Bact. aerogenes*, *Bacillus prodigiosus*, *B. proteus*, *Bacterium ichthyosmius*, *Pseudomonas liquefaciens fluorescens*, *Oidium lactis*. All organisms were inoculated singly and in various combinations, and the cultures were held at 20° C. for approximately nine months. At the end of that time the cultures were tested for the presence of trimethylamine by heating with alkali. Negative results were obtained from all of the lecithin inoculations tested. Unfortunately, many of the cultures were contaminated with mold, and, since the results could not be considered trustworthy, they were discarded.

The same series of experiments was repeated by inoculating 0.1-per-cent choline alone and in the presence of lactic acid and salt. These cultures were held under the same conditions as were the lecithin inocula-

tions. Trimethylamine was found where *Bacterium ichthyosmius* was inoculated alone, in combination with *Oidium lactis*, and with *Bacterium lactis acidi*. The presence of salt did not seem to prevent the production of trimethylamine. Two organisms which were isolated from milk gave a pronounced test from the choline inoculation, but gave negative results in the presence of lactic acid and salt; *Bacillus prodigiosus* gave a positive reaction from the choline alone; and *Bacterium aerogenes* gave a non-typical test under the same conditions, as did *Pseudomonas liquefaciens fluorescens*. All other inoculations gave negative results.

It would appear from the results of the inoculation experiments that since trimethylamine is produced from choline by *Bacterium ichthyosmius* and certain organisms found in milk, it is quite possible that the fishy flavor and odor found in milk and in butter may be due to this substance's having been produced from the choline of the lecithin molecule. The fact that the two organisms isolated from milk gave a positive reaction and that they were selected at random, indicates that such a fermentation might be found fairly often. These results would therefore seem to point to bacterial agencies as the cause of the fishy flavor, its manifestation in butter being dependent on conditions previously mentioned.

BACTERIAL INOCULATIONS INTO BUTTERFAT

A further attempt was made to produce the fishy flavor by bacterial inoculations into a medium in which all the constituents were fairly definitely known. Pure sterile butterfat from which the phosphatides had been extracted was used as the basis of such a medium. Four series of inoculations were made, using, with a few exceptions, the species that were inoculated into lecithin and choline. These inoculations were stored at a temperature of 0° F. or lower for two hundred and nineteen days, at the end of which time they were examined for the fishy flavor by four judges. Negative results were obtained from all inoculations, not one of the judges pronouncing any of the 120 samples to be fishy in flavor. Whether any of the samples had possessed the flavor at some time during the storage period is difficult to say. All of the samples had a disagreeable tallowy flavor and odor. The composition of each of the four series, and the variation in acid value caused by the inoculations, are shown in table 27. All samples contained from 10 to 12 per cent of moisture and 2 per cent of salt.

TABLE 27. COMPOSITION OF ARTIFICIAL BUTTER AND VARIATIONS IN ACID VALUE CAUSED BY BACTERIAL INOCULATIONS

Sample	Organism or source	Composition and acid value			
		Butterfat	Butterfat and 0.15 per cent of lecithin	Butterfat and Berkfeldt filtrate from starter	Butterfat, Berkfeldt filtrate from starter, and 0.15 per cent of lecithin
1	*Bacterium lactis acidi*........	5 2	6.1	6 5	8.8
2	*Oïdium lactis*...............	7 8	5 2	7.8	7.5
3	*Bacterium aerogenes*....... ..	7.1	6 8	5.8	7.8
4	*Bacterium ichthyosmius*...	5.2	6.8	6 1	7.1
5	*Pseudomonas liquefaciens fluorescens*....	6.8	7.1	7 1	7.1
6	*Bacillus prodigiosus*.........	8 4	6.5	7.5	7.1
7	*Bacillus proteus*.............	6.1	5 8	6 5	6.8
8	Fishy butter...............	7 1	7 1	7.5	7.8
9	Fishy butter................	6.1	9 1	6.5	7.5
10	Fishy butter...............	6.5	6 5	7 8	7.1
11	Fishy butter................	5.8	6 1	7 8	8.8
12	Fishy butter...............	7.1	6 1	8 8	8.1
13	Egg yolk..................	7 1	6 5	8 4	8.1
14	Egg yolk............... ..	7 1	6 5	8 8	9.7
15	Strong butter........... ..	9.1	6.8	8 4	7.8
16	Strong butter........... ..	8 4	8 1	8 4	8.4
17	Normal butter........	7 5	6 5	8.4	8.4
18	Fishy butter............ .	8 8	6.8	8.1	8 8
19	Fishy butter..	8.1	7 8	7 8	9.7
20	Fishy butter...	8 1	6 1	8 1	10.4
21	Fishy butter...	6 5	7.1	8 1	11 0
22	Fishy butter.	8 4	8 1	9.4	7.8
23	Fishy butter..	10 4	6 5	8.4	7.8
24	Egg yolk....	9 7	7 1	8 4	7.1
25	Egg yolk	8 8	7 1	6.5	7.8
26	Milk....	6.8	6.1	7 5	7.8
27	Milk.......	7.5	6 5	7.1	9.1
28	Milk.....	7 8	6.8	6.1	10.0
29	Milk..	6 5	8 1	8 1	5.8
30	Check... . .	5 8	5 9	8.1	7.4

The results shown in table 27 are of interest only to the extent that they show the variation in acid value caused by different species of bacteria. Inasmuch as the samples were placed in storage immediately after being inoculated, it is probable that the changes are the result of bacterial enzymes liberated by autolysis, because it has been repeatedly shown that little or no growth takes place during storage.

SUMMARY

The data presented in this paper show beyond a doubt that there is in normal butter a sufficient amount of lecithin to yield, on decomposition, small quantities of trimethylamine, and it is shown also that small quantities of this substance are essential for the manifestation of a fishy odor. Furthermore, it is shown that when this substance is worked into butter under the proper conditions, it produces a flavor described as fishy. These results are most uniform when trimethylamine butyrate is used. An associative fermentation in butter or in cream, with the ultimate formation of this substance, is quite possible. As to whether or not this or some other volatile and unstable combination of trimethylamine is the cause of the natural fishy flavor, remains to be shown more conclusively. Certain data do indicate that trimethylamine is found in some samples of fishy-flavored butter but not in others. Altho it is possible that its presence is incidental in such samples, that is not believed to be the case. In this connection it is worth while to call attention to the confusion between the fishy, oily, and metallic flavors when they are present to only a slight degree. It seems possible that the initiation of the development of these flavors depends on a common fundamental factor. Whether or not any particular one of them develops to its typical flavor would depend on the presence of certain conditions which were specific for that flavor. With this possibility in view, it would be logical to assume that trimethylamine is responsible for the typical herring, or mackerel, flavor and odor in butter, and that the absence of this substance would result in the manifestation of similar but non-typical flavors.

There seems to be no doubt that the presence of a definite acid condition in the butter is essential for the development of the fishy flavor. This condition is best obtained when butter is made from cream containing lactic acid, regardless of whether this is developed by bacteria or added to the cream in the form of the commercial product. Furthermore, the results indicate that, while a definite acid condition is essential, it must be accompanied by some other equally important factor. The data show that this factor is determined by biological agencies. It appears that both these factors must exist in a definite and delicate relationship, and that if the proper equilibrium is disturbed, the characteristic flavor is not manifest. Numerous results and observations indicate that the unknown transient factor is trimethylamine.

The bacteriological aspects of the problem seem to involve the determination of the relationship already mentioned. It is shown that the acid value of butter is to a certain extent regulated by biological factors, probably enzymes. It is shown also that trimethylamine may be produced in milk and in cream, probably to some extent from lecithin, with the consequent production of the fishy flavor in those products. Furthermore, it is shown that *Bacterium ichthyosmius,* which produced the flavor in those substances, would produce the flavor in butter also under certain conditions. It would therefore seem possible that other species of microorganisms might bring about the same type of change. It seems highly probable that the growth of bacteria in the cream before it is made into butter determines the conditions necessary for the later manifestation of the fishy flavor.

The data dealing with lecithin as the source of trimethylamine in milk products are too meager to warrant definite conclusions at this time. However, the results presented herein, taken together with what is known regarding this substance, indicate that this is one of the most logical sources.

ACKNOWLEDGMENTS

The author wishes to express his keen appreciation and gratitude to Dr. E. S. Guthrie, Mr. W. E. Ayres, and Mr. H. C. Jackson, of the Department of Dairy Industry at Cornell University, to all other members of this Department who have been kind enough to aid in the scoring of butter, and to all who have furnished samples for study.

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Memoir 26 [illegible], the third preceding number in this series of publications, was mailed on October 23, 1919.

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CORNELL UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

AN ECONOMIC STUDY OF FARM LAYOUT

W. I. MYERS

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CONTENTS

AN ECONOMIC STUDY OF FARM LAYOUT

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W. I. Myers

The investigation reported in this memoir had two objects. The first was to study the principles of farm layout, and determine their relative importance as an aid to individuals in rearranging their farms to secure the most efficient use of labor and land; the second was to study the utilization of land on the typical farms considered, as a public problem of land utilization, with particular reference to the possibilities of increasing the area of crop land to meet the needs of an increasing population.

Labor efficiency has always been the keynote of American agriculture. American farmers have wasted land but they have produced more product to the worker than any other farmers in the world. They have economized in labor, which was scarce, and wasted land, which was plentiful. The good free lands in North America are now practically exhausted and the pinch of land scarcity is beginning to be felt.

The future problem of American farmers is more difficult. It involves a better utilization of land, a greater intensity of cultivation, and, at the same time, the maintenance of a high productivity per worker. The last requirement is perhaps the most important, for, unless a high productivity per worker is maintained, the agricultural class will become a peasant class similar to that of European countries. Farm layout offers one means of saving land and labor. A properly planned farm layout should make the most advantageous utilization of the land, and at the same time secure the greatest efficiency of labor.

LOCATION AND DESCRIPTION OF FARMS STUDIED

For several years the Department of Farm Management of the New York State College of Agriculture has been conducting cost-accounting investigations on New York farms, in cooperation with the Office of Farm Management of the United States Department of Agriculture.

[illegible] These studies were made under the direction of Professors G F Warren an[illegible] [illegible]rtment of Agricultural Economics and Farm Management at Cornell U[illegible] and C. V Noble assisted in mapping the farms. Surveying instruments were furnished by the Department of Rural Engineering. [illegible] were traced and lettered by Miss C. L. Garrett, Professor J [illegible] and Professor J. L [illegible] these and to all others who have cooperated in the work, the writer is indebted.

Since 1915 annual maps of the farms on which cost accounts were being kept have been made by the writer, primarily to increase the value and accuracy of the accounts. Blue prints of the farm maps were returned to each farmer for his own use. The data for the following studies of farm layout were obtained from these maps, supplemented by information furnished by the farmers and in some cases by data from the cost accounts.

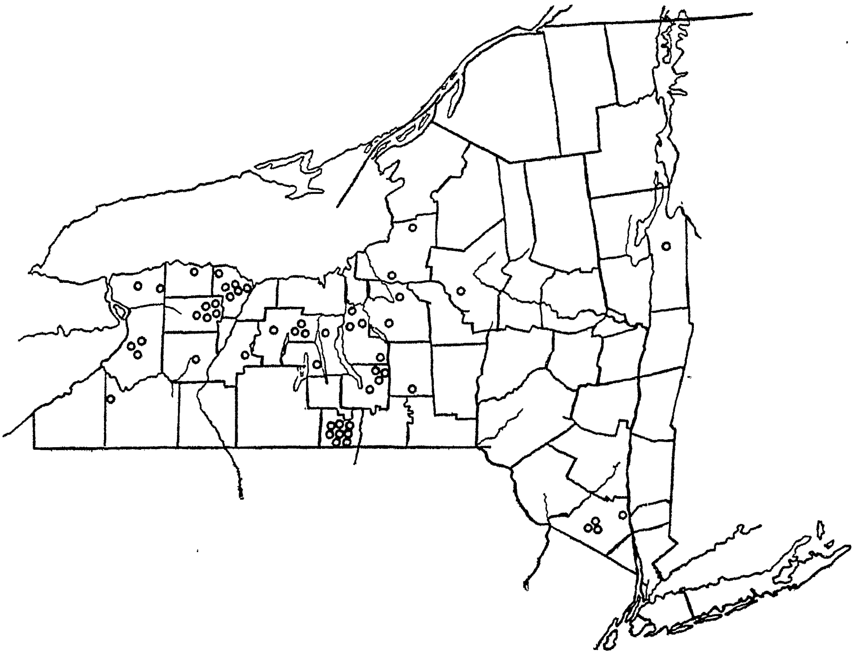


FIG. 67. LOCATION OF FARMS STUDIED

The location of the fifty-three farms considered in these studies is shown in figure 67. Most of these farms are larger than the average farm, their average area being 173.4 acres as compared with an average of 103.2 acres for the farms reported in the state census of agriculture for 1918. Altho larger, better organized, better managed, and more profitable than the average farm, they are all real farms, on which the operator is a laborer.

Most of the important types of farming in New York State are represented among the farms studied. Twenty-four of the farms are located in western New York. These farms are devoted largely to fruit and general farm crops. Some fruit is grown for sale on nearly all of them, while ten are intensive fruit farms. Two of the farms in this region produce truck crops for the Buffalo market. Little stock is kept in this region, only two farms having more than six cows. Eleven farms are located in southern New York. Dairying is here the principal enterprise and few crops are grown for sale. Two of the farms in this region raise some truck crops for local markets, and two farms grow some tobacco. Twelve farms are located in the general farming region of central New York. Dairying is an important enterprise on these farms, but considerable quantities of various crops are grown for sale. Four farms are located in southeastern New York. Three of these are intensive dairy farms, while the fourth, in the Hudson Valley, produces fruit and truck crops for local markets.

METHODS OF INVESTIGATION

In mapping these farms, many different methods were tried in an effort to combine a reasonable degree of accuracy with speed. The first farms were mapped with only a 100-foot steel tape, all lines and any necessary angles being measured. Where farms are rectangular in outline, with rectangular fields, this method is the most rapid and satisfactory. Where farm or fence lines are crooked it is impracticable, and, since most New York farms are at least partly irregular, some means must be found to map these irregular lines. Hand compasses and general-purpose levels were tried and discarded. The method that was found most satisfactory was to use a steel tape for measuring the boundaries and all straight lines in a farm, and a surveyor's transit for mapping the irregular parts. On most farms it was necessary to run only a short traverse with a transit, locating the corners of all irregular lines accessible from each station by the horizontal angle and the distance to each. All distances were read by stadia. When targets are used, this method is both rapid and accurate. In all cases the present farm fences were mapped, and no effort was made to run out the deed lines. Deed descriptions were obtained in some cases for checking purposes, but in many deeds the descriptions were inaccurate.

In addition to the measurements of the different parts of the farms, other data were obtained in the mapping. Every change in the kind of fence was recorded in the field notes, and from this record the kinds of fence, and the number of rods of each kind on every farm, were found. The width of the strip of land occupied by each kind of fence, with different crops, was measured. Where the width of the strip varied along the edge of a field, the average width was estimated and checked by frequent measurements. The area of the land in crop fields occupied by swampy spots, streams, open ditches, driveways, trees, stone outcrops, stone piles, and barns was measured, as well as the crop land untillable because rough, or wasted because of proximity to woods. All important buildings and the divisions of the farmstead were measured and located. Where possible, the history of the fields and the farm was learned from the owner. Data were obtained on the character of the pasture land. Woodlots were located, and notes were taken on the suitability of the land for other purposes. Orchards were classified by kinds, and as to whether or not they were bearing. In short, an effort was made to get as complete information as possible concerning the utilization of all the land on these farms.

The farm maps were drawn to a uniform scale of 200 feet to the inch. Except for very large and very small farms, these proportions are satisfactory. In addition to farm and field lines, the kinds of fence and all the physical features of the farm were shown on the maps. This necessitated the provisions of a set of symbols which could be drawn rapidly. Some ideas for these symbols were obtained from the conventional signs adopted as recommended practice by the American Society of Agricultural Engineers. The symbols used are shown in figure 68.

Areas of fields and other farm divisions were obtained from the maps by the use of a planimeter. After ascertaining an area in square inches by averaging four or five observations of the planimeter, this area was reduced to square feet and then to acres. The area of each crop field was designated by two figures, the top figure representing the gross area included within the boundaries of the field, and the lower figure the area actually in crops, after deducting the land occupied by fences, stone piles, streams, and other obstructions.

The accuracy of the maps and of the areas of the different divisions in all cases was checked by observation by the farmers. The areas of

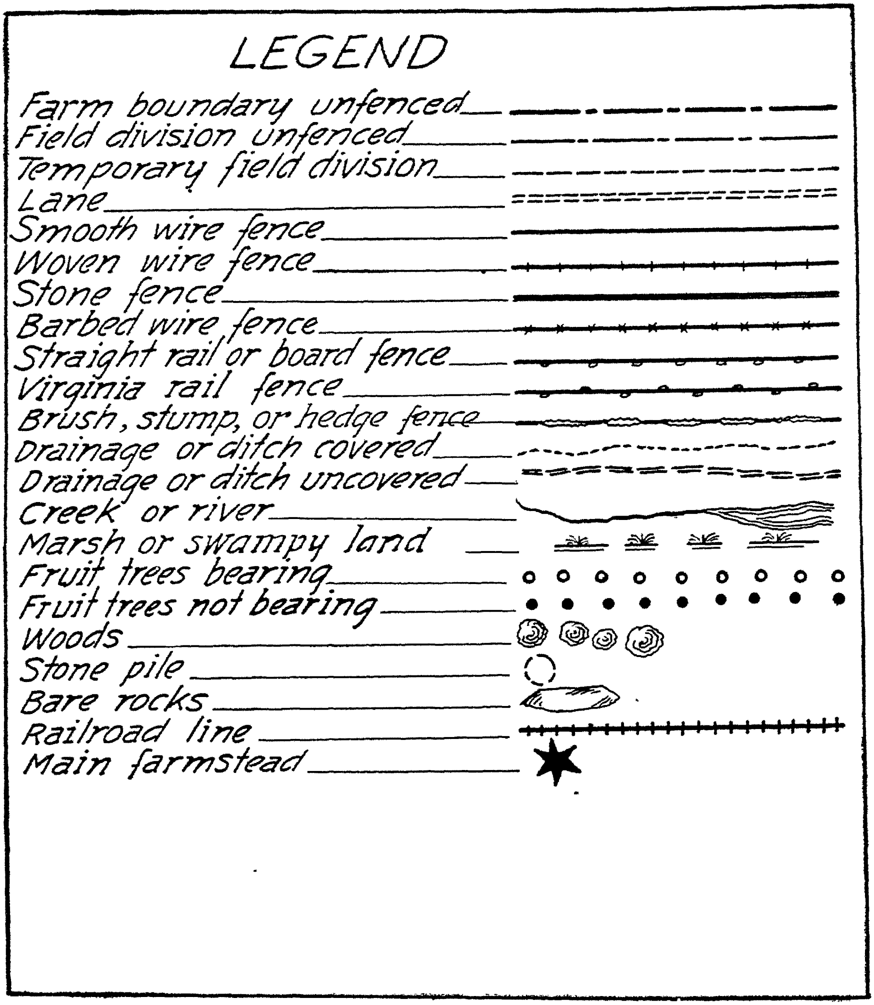


FIG. 68. SYMBOLS USED IN MAPPING FARMS

fields were roughly checked by comparison with farmers' estimates previously made. The areas of the farms were also checked by comparison with the acreages as given in the deeds. The best check on the accuracy of the methods employed was obtained by comparing the total area of

the farm, as computed from the measured dimensions, with the sum of the areas of the different farm fields taken from the map by the use of the planimeter. This method of checking gave the combined error in drawing the maps to scale and in figuring the acreages. For fourteen rectangular farms that were thus checked, the average variation of the sum of the areas of the farm fields from the computed area of the farm was one-fifth of one per cent, the maximum variation being less than one-half of one per cent. Some farms nearly rectangular in shape were checked by completing the rectangle, adding the additional area to the farm area, and comparing this total with the area of the rectangle as computed from the dimensions. This method, however, checks only the accuracy of the planimeter areas.

In most cases the present farm areas, as thus determined, overran the deed acreages. Of thirty-eight farms for which the deeds and the measured areas were compared, thirty-one overran the deed acreage, the average overrun being 3.5 per cent. The average variation of all these thirty-eight farms was 3.1 per cent from the deed acreage.

In these studies a field is considered to be all the land usually farmed as a unit. In comparing layouts of different farms in the following pages, the average size of the farmed fields and the average distance to these fields are usually given. In computing the average size of the fields for each farm, the area in field crops was divided by the number of fields usually farmed. In computing the average distance to fields, the usual line of travel to the fields was measured. Both the distance to the nearest gates and the distance to the centers of crop fields were measured, but, since with most farm operations unproductive travel ends at the gate, the former figure is used herein unless otherwise indicated. In all cases the average distance to fields for each farm is the weighted average distance.

The total estimated acreage of 380 farm fields, as given by farmers, varied from their measured acreage by less than two-fifths of one per cent. Farmers ordinarily estimate areas in acres and fractions of an acre, seldom trying to estimate closer than a half acre, while the measured areas were computed to the nearest one-hundredth of an acre. For this reason the percentage variation of estimated from measured areas of single fields was high with small fields. With fields of less than two acres, the average variation of individual estimates from measured areas was about nineteen per cent. The average variation of the estimates decreased with larger fields up to 20 acres. With fields from 12.1 to 20 acres in size, the average

variation of individual estimates from measured areas was about seven per cent. With all sizes of fields the number of over-estimates was approximately equal to the number of under-estimates, and, as in other cases where judgment is unbiased, the errors were compensating.

HOW FARM LAYOUTS HAVE DEVELOPED

Practically all of the land in New York farms was originally covered with forests. A large part of this land was more or less stony. These factors made the task of clearing the land for cultivation a long and laborious one, and their effect can be plainly seen on the layout of farms today.

The first task of the settler was to provide a shelter for himself and his family. In deciding on a location for his farmstead, little or no attention was paid to its convenience as a center for farm operations. The most important considerations were that the buildings should be near a supply of good water, preferably a spring, and that they should be accessible to the roads then in use.

After shelter had been provided, the next task of the settler was to clear the land for cultivation. The drier, warmer parts of the farm were usually cleared first. The shape of these clearings, and the directions of their boundaries, were often matters of chance. After cutting and burning the trees and brush until a patch of sufficient size had been cleared, the settler removed the surplus surface stones, piling or throwing them around the edge of the clearing. Crops could then be grown between the tree stumps until the roots rotted so that they could be pulled. Other patches were successively cleared in the same haphazard fashion, and fences of rails, stumps, or stones, or of combinations of these materials, were built between them. Small, irregular fields were the natural result of clearing land under these conditions. In some cases the fences were made parallel with the farm boundaries, but oftener they were not. These small, irregular fields were not a serious drawback to cultivation with the hand-labor methods then existing. Mowing was done with a scythe, and reaping with a cradle. Grain was sown broadcast by hand and most of the cultivating was done with a hoe. A two-acre field was probably as large in terms of human labor as a ten-acre field is to-day. Neither were these small, irregular fields difficult to fence. With rail, stump, or stone fences, the irregularity of the fields made little difference.

Another factor that has influenced the development of farm layouts is the size of grants of land made to the early settlers. Examination of the original deeds of many New York farms has shown that much of the farm land of New York was sold or given to settlers in small tracts of from 50 to 100 acres. The general plan followed in making grants to settlers was to give each settler enough land to maintain a family. The few large grants made in very early times to Dutch patroons in eastern New York were cut up into family farms owned by the men who tilled them. The ideal was the family farm, and consequently most of the farm land available for settlement was divided into tracts of a size deemed sufficient for maintaining a family. The amount of land necessary for this purpose varies widely according to the natural productivity of the soil, but, since little was known of the relative productivity of the soil in different regions, little allowance appears to have been made for this factor in laying out farms for settlement. A large farm could not be cleared and worked by a single family with hand-labor methods. Furthermore, in these newly settled regions the settler's family did not have to rely entirely on the productivity of the soil for their living. Lumbering offered an opportunity of earning money during the winter months, and thus helped to maintain the family while the land was being cleared for farming.

In laying out farms for settlement, little attention was paid to making them of such shape as to be conveniently worked. In eastern New York the original farms were often irregular in outline. In central and western New York most of the farms were rectangular in shape, but the 50-acre farms were made in some counties about 50 by 160 rods, in other counties 33 by 240 rods. With such long, narrow farms, a large part of the land is remote from the buildings and much labor is wasted in travel.

After most of New York was settled, important changes took place in farming practice, due principally to the use of labor-saving machinery. The invention and use of the mower, the reaper, the drill, and other labor-saving tools greatly increased the effectiveness of human labor and consequently the area of land that could be farmed by one person. The small, irregular fields which had resulted partly from the accidents of clearing and partly from topography, were a serious handicap to the use of machinery. Stones, stone piles, and other obstructions added to the difficulty of working these small, irregular fields with machinery. Steep slopes which had been mowed easily with a scythe or a cradle could not

be cut with a mower or a reaper. The opening-up of the Middle West about this time made available large areas of level fertile soil, and farm land not adapted to machine cultivation could not compete successfully in crop production with these favored regions. Some entire farms were abandoned. On many farms, fields not adapted to machine production were changed to pasture land.

Since the use of labor-saving machinery enabled them to work larger areas than the original small farms, farmers began to combine two or more of these small farms into larger farm units. The extension of the use of machinery has continued down to the present day, and an increase in the size of farms has followed as a natural result. The numbers of farms of different sizes as reported in the federal censuses since 1860 are shown in table 1:

TABLE 1. CHANGES IN SIZE OF FARMS IN NEW YORK STATE AS SHOWN BY UNITED STATES CENSUS REPORTS FROM 1860 TO 1910

Size of farms (acres)	Number of farms					
	1910	1900	1890	1880	1870	1860
Under 10	18,655	16,760	13,166	14,913	13,078	6,763
10–99	103,401	114,694	120,569	128,276	146,982	139,849
100–499	92,194	93,909	91,323	96,273	55,948	50,132
500 or over	1,347	1,357	1,165	1,596	245	246
Total number of farms	215,597	226,720	226,223	241,058	216,253	196,990
Average size of farms (acres)	102	100	97	99	97	106

Apparently the average size of New York farms as reported by the census has not been increasing. The number of so-called "farms" of less than 10 acres has increased greatly since 1860; the number of farms of from 10 to 99 acres has decreased; while the number of farms of 100 acres or more has increased. The increase in the numbers of small "farms" has tended to offset the effect of the increased number of moderately large farms, and as a result there has been little change in the average size of the "census" farm. Very many of the places of less than 10 acres are not real farms on which the operators make their living, but

are homes for persons engaged in industry. There is no doubt that the average size of the general farms in New York has increased considerably during this period.

As a result of these changes, many present-day farms are compounds or complexes of original smaller farms or parts of farms. The fifty-three typical farms included in this study were composed of at least one hundred and twenty-six smaller farms or parts of farms, to the knowledge of their present owners. The number of farms composed of one, two, three, four, or more parts is shown in table 2:

TABLE 2. COMPOSITION OF PRESENT-DAY FARMS

Size of farms (acres)	Total number of farms	Number of farms made up of						
		One part only	Two parts	Three parts	Four parts	Five parts	Fifteen parts	Twenty-two parts
Less than 100	13	8	2	2	1	0	0	0
100–174.9	20	11	5	2	0	1	0	1
175 or over	20	3	6	4	5	1	1	0
All farms	53	22	13	8	6	2	1	1

Three-fifths of the fifty-three farms were made up of two or more original farms or parts of farms. One large farm of 478 acres was made up of fifteen distinct farms or parts of farms ranging in size from 10 to 120 acres. Another farm of 150 acres was made up of twenty-two parts.

The process by which the small original farms have been combined into larger farm units can best be illustrated by maps showing different stages in the development of typical farms. The outlines of five farms in central New York as they appeared when settled between 1800 and 1835 are shown by figure 69. Farms A, B, and C were distinct, complete 50-acre farms settled by different men; D was a tract of 50 acres forming a part of a larger farm; and E was a 12-acre lot which was a part of a fifth farm. Log houses and barns were built on farms A, B, and C on the locations shown. The north ends of these farms were cleared first. About 1845 the main road was put thru south of B, C, and D, and at about the same time farm C was sold by its first owner. The new owner of

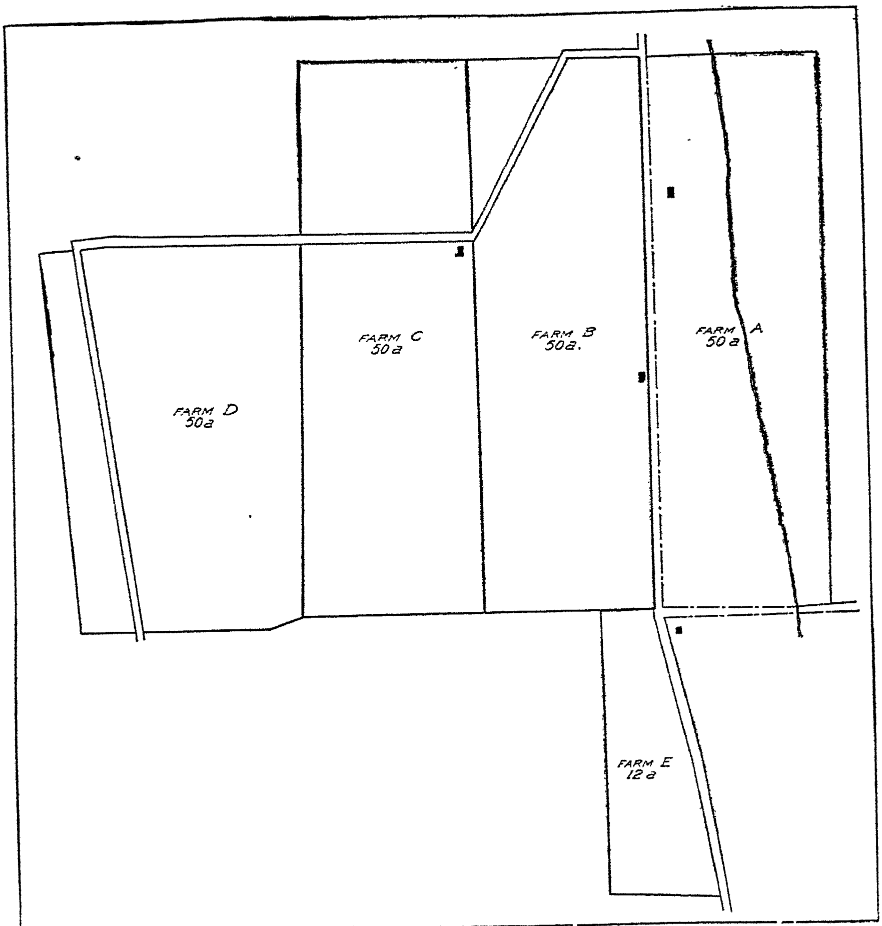


Fig. 69. Development of a Central New York Farm -
Original plan, showing outlines of farms A, B, C, D, and E when settled

farm C never lived in the original log house at the north end of the farm, but changed the location of the farmstead to the extreme southeastern corner of this farm on the new road. He moved the original barn to the new farmstead and built a new house, living for a time during the summer in the old barn while the house was under construction. After clearing the south end of farm C, this man began the present consolidation by buying 25 acres of D, on the west of his farm. After clearing this he bought the remaining 25 acres of D. About this time the road running north thru farm D was moved west to its present location as the western boundary of this farm, in order to avoid a steep hill, and the road running across the north ends of farms B and C was abandoned.

The owner of farm CD died and the land was inherited by a son who continued the process of combination begun by his father. He first bought farm B, on the east of the farm inherited. This made him the owner of three of the original 50-acre farms, B, C, and D. The 12-acre lot E also came under his management thru inheritance by his wife. After cutting the remainder of the timber from farm B, the owner of farms B, C, D, and E took advantage of a good opportunity and sold this farm.

The location of the farmstead of farm C was in the southeastern corner of the farm, adjoining one of the crop fields of farm B. Because of this proximity, poultry from the farmstead of farm C did more or less damage to the crops in the adjoining field and caused some ill feeling between the neighbors. Partly to avoid this difficulty, and partly because it was a better field, the owner of farms B, C, D, and E retained this 10-acre field in selling farm B, and sold instead a larger field from the north end of farm C. The outline of the farms at this stage of their development is shown by figure 70.

In 1899 farms C, D, and E were purchased by the present owner. Two years later this farmer bought farm A, which had been an independent unit up to this time. In 1918 he bought farm B, thus bringing under one management land which was in five different farms eighty years earlier. The last two stages in the development of this farm are shown in figures 71 and 72. The area of the combined farms is 216 acres, a moderately large family farm. Probably it is no larger in terms of human labor than a similar farm of half the area eighty years ago.

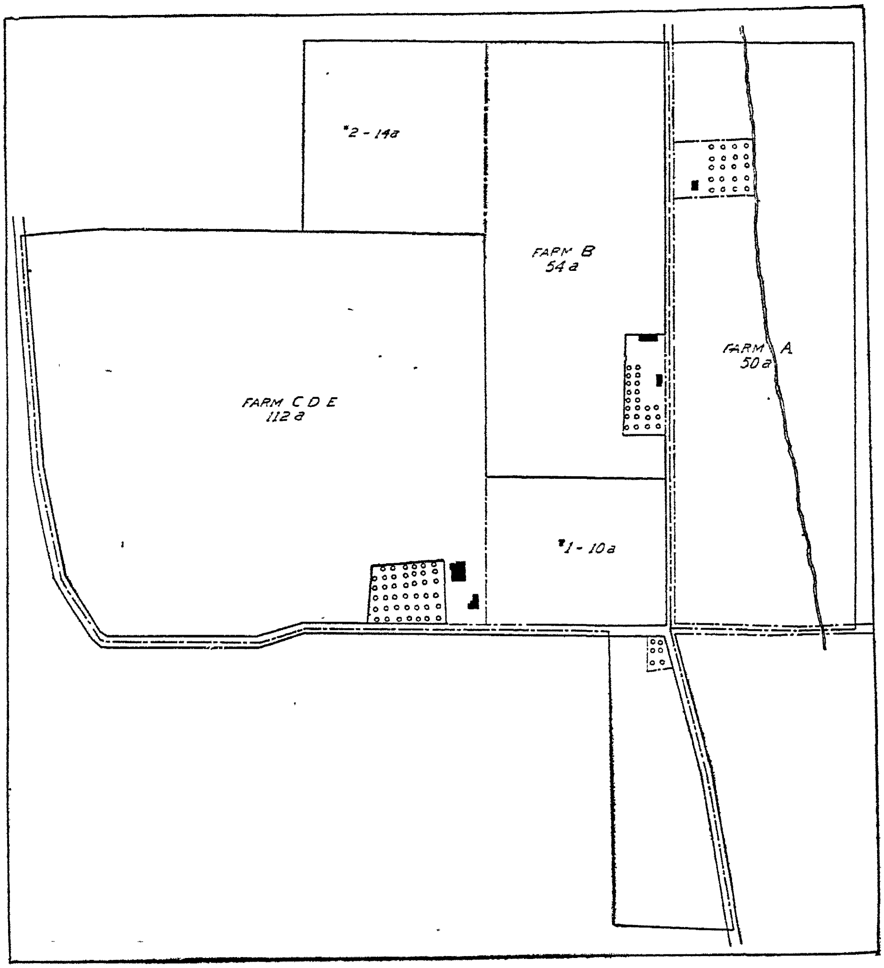
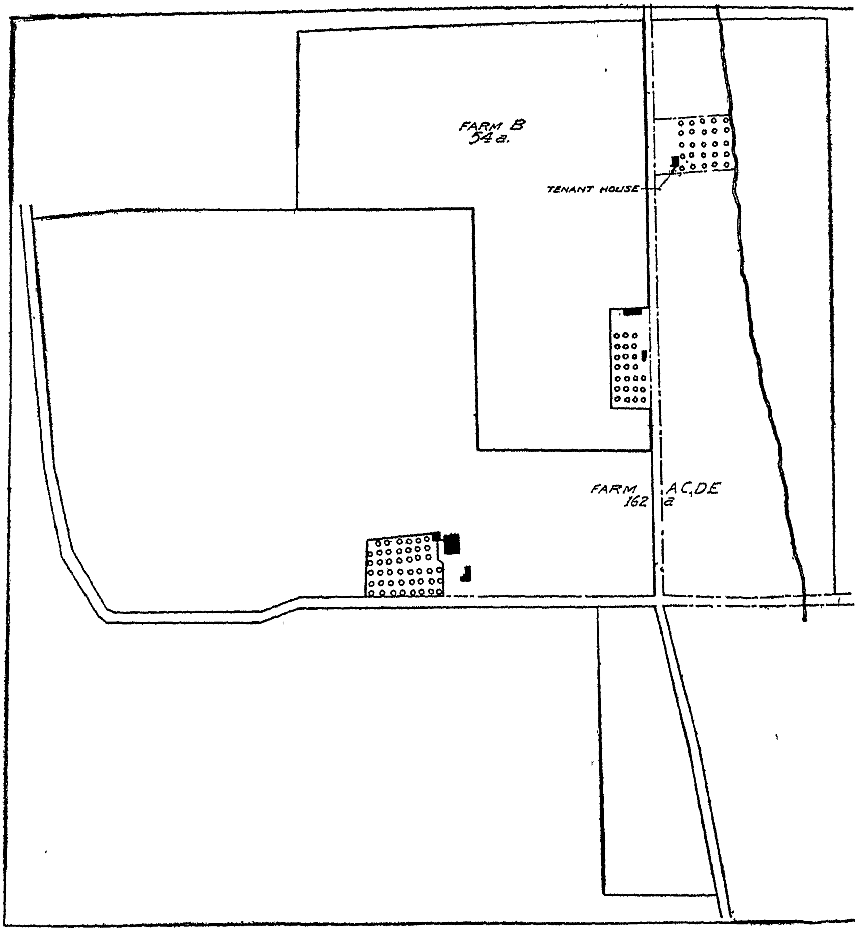


FIG. 70. DEVELOPMENT OF A CENTRAL NEW YORK FARM — II

The original farms C, D, and E have been combined, but A and B are separate farm units



[FIG. 71. DEVELOPMENT OF A CENTRAL NEW YORK FARM — III

In 1899 farm CDE was purchased by the present owner and two years later farm A was added, making the combined farm area 162 acres

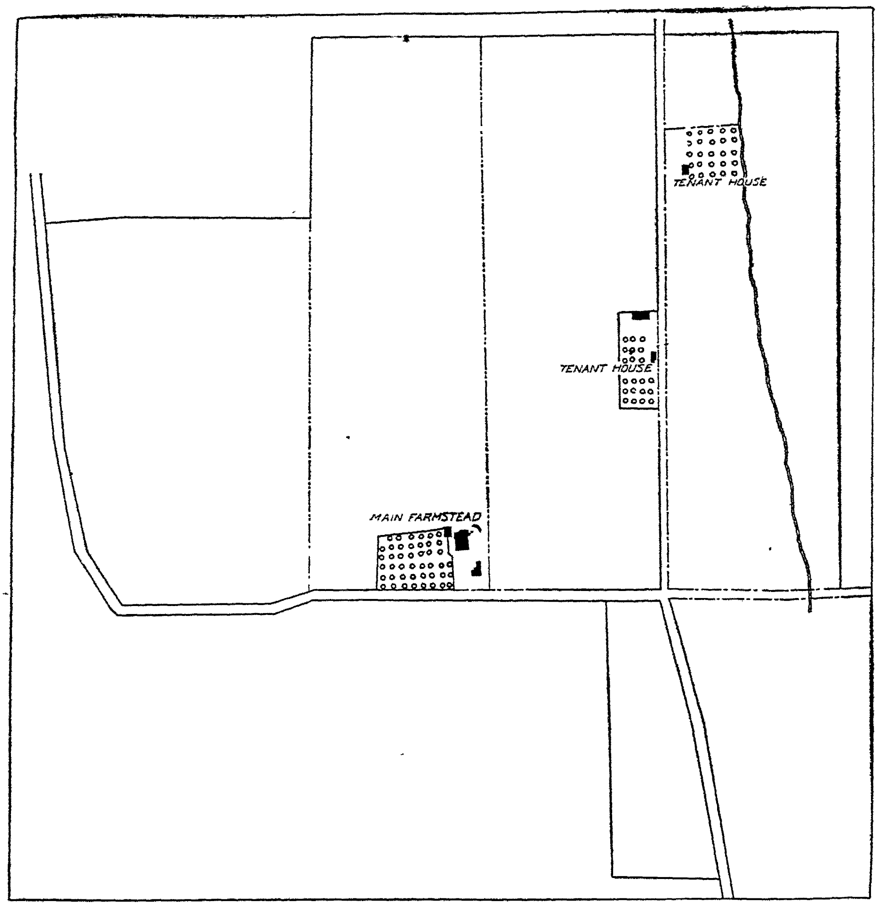


Fig. 72. DEVELOPMENT OF A CENTRAL NEW YORK FARM — IV

In 1918 farm B was purchased, thus bringing the five small original farms into one farm of 216 acres

This is not an isolated case. A similar process has been going on in all parts of the State as the development of farm machinery has increased the effectiveness of human labor and consequently the area of land that can be farmed to best advantage by one family. Other forces, however, are pulling against this tendency to increase the size of farms. Every farm changes hands at least once in a generation. Tenants and other persons of small means often wish to buy small farms at first, because of lack of capital, with the expectation of buying more land later if successful. There is also a constant tendency to divide farms among the heirs when

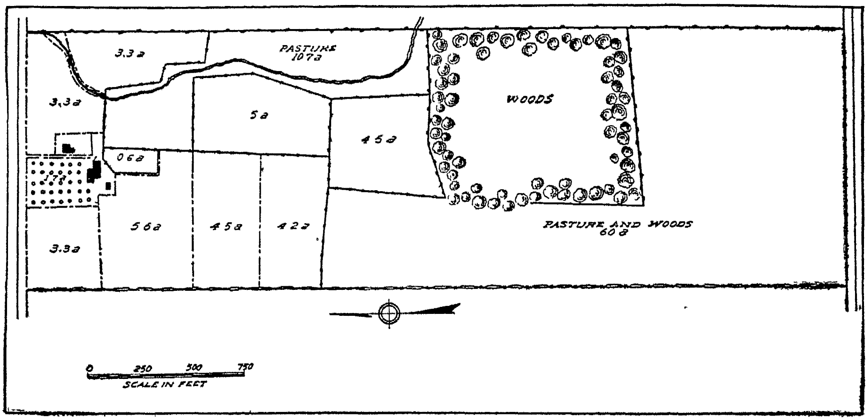


FIG. 73. PLAN OF A WESTERN NEW YORK FARM IN 1906

The area of the farm at this time was 110 acres, 35 acres having already been added to the original 75-acre farm

farms change hands by inheritance. The result of these conflicting forces is a slow increase in the average size of farms.

The plan of a western New York farm in 1906 is shown in figure 73. The area of the farm was then about 110 acres, 35 acres having been added to the original farm of 75 acres before that time. In this vicinity much of the land was surveyed into rectangular farms of from 50 to 100 acres, three-quarters of a mile long. Such long, narrow farms were never adapted to economical operation. Land at the end of one farm, three-quarters of a mile from the buildings and too remote for economical operation, is usually directly across the road from the farmstead of another

farm which in turn has fields three-quarters of a mile away. This mistake in laying out farms has cost New York farmers many thousands of dollars in lost time traveling to and from remote fields.

In 1907 an adjoining farm of 65 acres was added to the farm just mentioned. The plan of this larger farm of 175 acres is shown in figure 74. No further change was made in the size of this farm until 1917, when the 100-acre farm across the road was rented and added to the 175 acres

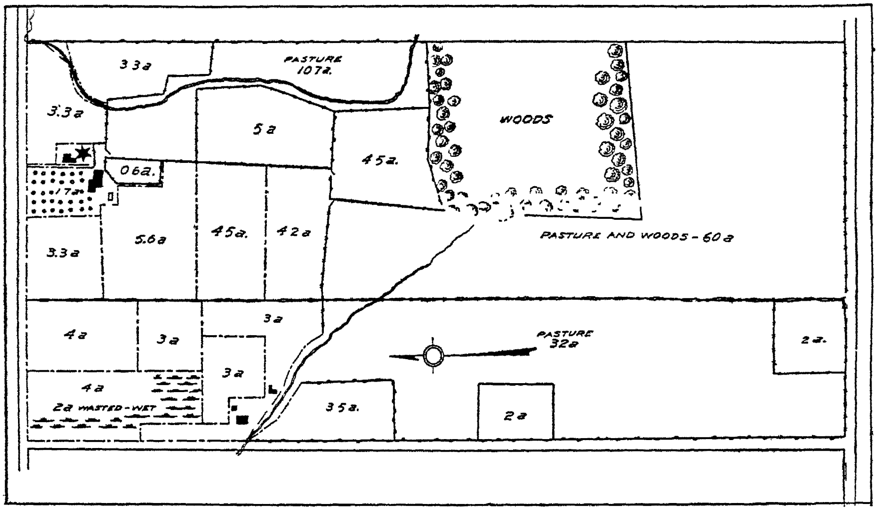


FIG. 74. PLAN OF THE SAME FARM IN 1907

The area of the farm at this time was 175.8 acres, the adjoining farm of 65 acres having been acquired by purchase

already owned. The plan of the combined farms is shown in figure 75. It is probable that the smaller farm will be purchased within a few years and made a permanent part of the larger farm, since it would be more valuable as a part of this farm than as an independent unit. In this region a farm of 100 acres is too small for economic operation, because a large part of the land is so rough or so wet as to be adapted only for pasture. The area of crop land in this 100-acre farm, 37 acres, is too small to allow of efficient use of labor and machinery with general farm crops when farmed independently, and the land is not adapted to intensive

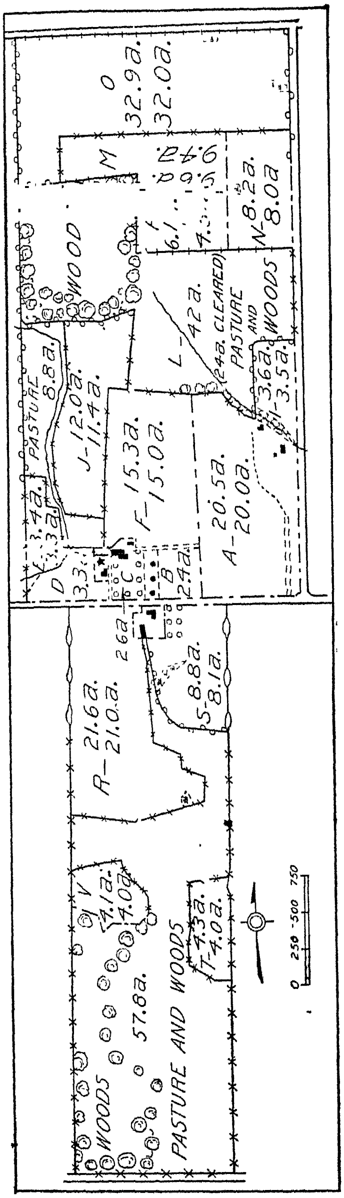


FIG. 75. PLAN OF THE SAME FARM IN 1918

In 1917 the unprofitable 100-acre farm across the road was added by rental, making the present farm area 275 acres

cropping. In this case the small farm makes a valuable adjunct to the larger farm. The pasture is needed in pasturing the large herd of cows kept on the larger farm. The barn is convenient for keeping young stock thru the winter, and the house is well located for the home of a hired man. The crop land is convenient to the farmstead of the larger farm. The present farm of 275 acres is not too large for a family farm in this region. It is smaller in terms of human labor than the 216-acre farm whose history is given in the preceding pages.

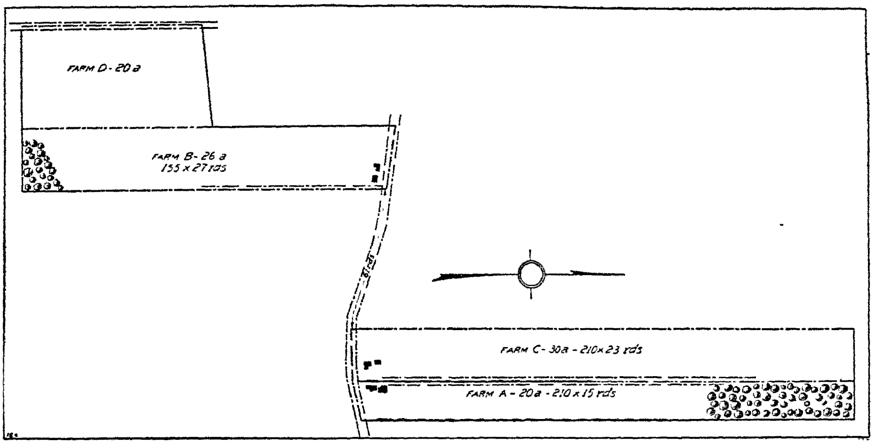


FIG. 76. PLAN OF A WESTERN NEW YORK FRUIT FARM IN 1917 SHOWING THE ORIGINAL FARMS THAT HAVE BEEN COMBINED INTO ONE FARM BUSINESS

The very long, narrow farms found in this region are inconvenient to work and result in much wasted labor

In this process of combining farms to keep pace with changing conditions, it has not always been possible to procure land adjacent to the farm already owned. The plans of four farms in western New York which have been combined into one farm business are shown in figure 76. In this region the farm land was first surveyed into areas of 160 acres, and these were later cut up into small farms of from 20 to 50 acres. Because of the value of frontage on the main highway along which these farms are located, the small farms were made very long and narrow. Farm A was an extreme example of this arrangement, being more than 200 rods long and only 15 rods wide. Such a layout is economical of

road frontage but extremely wasteful of labor, land, and fencing. The long distance which must be traveled to the remote fields of even a 20-acre farm is readily apparent. Furthermore, with the type of fence used on many of these farms this arrangement is very wasteful of land. The present owner of these farms bought the two farms A and B in 1888. At this time large osage-orange hedges formed the eastern boundary of farm A, and also the line between farms A and C. These hedges wasted more than a rod of land on each side. In addition a driveway was necessary to give access to the back fields. The two hedgerows and the driveway made untillable about one-sixth of the area of farm A as far back as they extended. In 1904 farm C was added to farms A and B, making the farm area 76 acres. Having control of farms A and C, this farmer pulled out the hedge between them, thereby gaining about an acre and a quarter of land as well as eliminating one driveway. In 1916 farm D, of 20 acres, was added, bringing the farm up to the size here shown. Further additions have since been made.

This farm is located in one of the most prosperous agricultural regions of the State. The land is largely devoted to fruit and other intensive crops. The accessibility of the fields from the farmstead is far more important under these conditions than where only extensive crops are grown. Altho much smaller in area, this farm is larger in terms of human labor than the 275-acre farm discussed just previously.

A farm representing an extreme case, in which twenty-two parcels of land have been combined to form one farm of 150 acres, is shown in figure 77. Some of these parcels were town lots of the decadent village in which the farm is located. The scattered, patchwork appearance of this farm shows the difficulties that have been encountered in trying to procure enough land to make a farm of reasonable size.

The foregoing examples are intended to give typical illustrations of the combination of farms in response to changing methods of production. Not all farms are composed of as many parts as the examples given. These farms are larger today than the average farm, and hence they would be expected to be made up of more parts.

As larger and more improved machines come into use, the problem of rearranging farms to permit the economical use of machinery becomes more important. Every new, improved farm machine is a new argument for a better farm layout. The newest farm machine, the tractor, is no

exception to this rule. One of the striking facts brought out by an investigation of tractors in Illinois[1] is that a third of the tractor owners increased the size of their farms after purchasing tractors. In so far as tractors come to be used in this State, it may be expected that they will tend to continue the

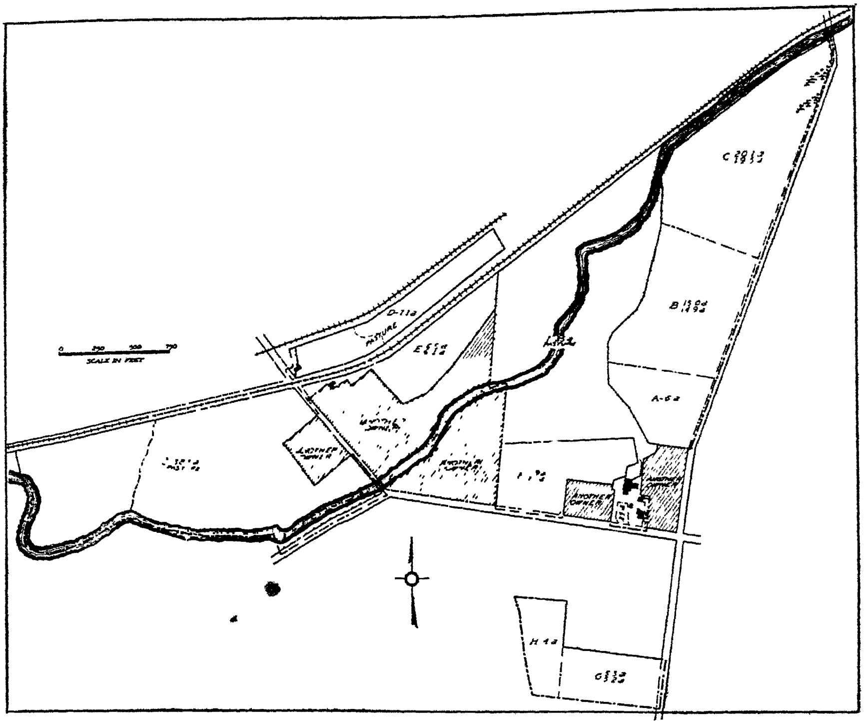


FIG. 77. PLAN OF A SOUTHERN NEW YORK FARM

This farm represents an extreme case in which twenty-two parcels of land have been combined to form one farm of 154.3 acres. The scattered, patchwork appearance of this farm shows the difficulties that have been encountered in trying to acquire enough land to make a farm of reasonable size

process of combination of farms begun when the first labor-saving machine came into use, nearly a century ago. It may also reasonably be expected that the tractor will give greater impetus to the rearrangement of farms, because large fields are necessary for economical operation.

[1] Tractor experience in Illinois, page 7. By Arnold P. Yerkes and L. M. Church. U. S. Dept. Agr. Farmers' bul 963. 1918.

The response to the conditions that have made desirable some rearrangement of farms has been varied. A few persons have rearranged farms too rapidly, giving undue importance to this phase of farm management and often incurring greater expense in making the rearrangement than is justified by the saving to be made. To this class of persons would belong many rich men, some over-enthusiastic students, and a few farmers. On the other hand, most farmers have not made these readjustments as rapidly as would probably be justified. Agricultural conditions for the decade preceding 1915 justified a more rapid rearrangement of farm layouts than any other period since the Civil War, and these conditions may reasonably be expected to continue.

The layout of a farm is far from being the most important factor for success in farm management. For this reason the improvements of farm layout should always be subsidiary to the main business of farming, which is the producing of food. Plans for a satisfactory rearrangement require much thought and time. Both the changes to be made and the order in which they are to be made should be determined in advance. Any one planning to rearrange a farm should be very sure of his plans and then should proceed slowly.

FARM LAYOUT

SIZE OF FIELDS

The most important factor in the layout of farms is the size of the farmed fields. Size of fields affects not only the efficiency of labor, but also the economy of fencing and of land.

Effect of size of fields on labor

The most important effect of size of fields is on the labor required for the different field operations. For economy of labor, fields should be large. The importance of size of fields as affecting labor depends on the number of horses driven, and on the operation to be performed. The negro with one mule can farm small fields, but when three- to six-horse teams are used, fields should be large. With tractors it is even more important that fields should be large. It is more important to have large fields for plowing than for mowing. Large fields are not usually mowed all at once, but in two or more parts.

In order to determine the effect of size of fields on the labor required for various farm operations, a study was made of the labor records, for the years

1914 to 1917, of the farms on which cost accounts have been kept by the owners in cooperation with the New York State College of Agriculture and the Office of Farm Management of the United States Department of Agriculture. In these cost accounts an account is kept with each crop rather than with each field. On many farms two or more fields of the same crop are produced and the labor records for the different fields are not kept separate. For this study, only those records were included in which only one field of a given crop was grown, or in which the records of the different fields had been kept separate. In all cases the data are actual time records kept by farmers. The effect of size of fields on the labor required for various farm operations is shown by tables 3 to 8. In considering the results of these tables it should be borne in mind that the larger fields are

TABLE 3. RELATION OF SIZE OF FIELDS TO LABOR REQUIRED TO PLOW AN ACRE

Size of fields (acres)	Number of fields	Average size of fields (acres)	Average length of fields (rods)	Time required to plow one acre	
				Man hours	Horse hours
Less than 2	40	1.02	20.6	8 5	19 8
2–4.9	57	3.48	34.6	6.5	15 0
5–9 9	78	7.24	49.9	6.2	16.2
10–14.9	40	11.68	54.7	5.7	14.3
15 or more	27	20.26	77.9	5.1	13.2
Total	242	....	......	....	....
Average	.. . .	7 51	45.4	5 8	14.8

usually found in regions of more level topography. Large fields are usually found also on the larger farms. Since both of these correlated factors have an effect on the labor required for various farm operations, it is probable that the results due to size of fields alone are less than the figures indicate.

Apparently the saving of labor in plowing effected with larger fields, as shown in table 3, is not due to the use of more horses per team, since there is little variation in the average number of horses per man between the smallest and the largest fields. One of the reasons for the saving of labor with large fields is the time lost in turning in small fields. If the fields

were plowed with a 14-inch plow, 110 turns to the acre would be required in plowing fields of 1 acre, but only 29 turns to the acre would be required in the 27-acre fields. The necessary time required to turn a three-horse team and the plow, and get ready to start back, was found to average about a half minute. In addition to the time necessarily lost in turning, there is a tendency to rest oftener when turns are frequent.

TABLE 4. RELATION OF SIZE OF FIELDS TO LABOR REQUIRED TO ROLL AN ACRE

Size of fields (acres)	Number of fields	Average size of fields (acres)	Average length of fields (rods)	Time required to roll one acre	
				Man hours	Horse hours
Less than 3	9	1.58	22.6	1.18	2.36
3-4.9	15	3.91	41.2	0.95	1.90
5-9 9	29	7.47	49.8	0.68	1.36
10-14 9	11	11.69	48.5	0.77	1.54
15 or more	12	20.97	85.9	0.65	1.30
Total	76	....	....	....	....
Average	....	8 81	50.4	0.72	1.44

The saving of time in rolling large fields (table 4) is proportionately as great as that in plowing large fields, but, since rolling is a rapid operation, the total hours saved per acre are less in rolling than in plowing.

TABLE 5. RELATION OF SIZE OF FIELDS TO LABOR REQUIRED TO DRILL AN ACRE

Size of fields (acres)	Number of fields	Average size of fields (acres)	Average length of fields (rods)	Time required to drill one acre	
				Man hours	Horse hours
Less than 2	9	1.07	20.4	1.93	3.86
2-4 9	29	3.47	36.7	1.36	2.72
5-9.9	45	7.29	51.3	1.10	2.20
10-14.9	21	11.75	53.7	1.04	2 08
15 or more	16	21.91	82.2	1.01	2.02
Total	120	....	....	....	....
Average	....	8.63	50.0	1.09	2.18

TABLE 6. RELATION OF SIZE OF FIELDS TO LABOR REQUIRED TO MOW AN ACRE

Size of fields (acres)	Number of fields	Average size of fields (acres)	Average length of fields (rods)	Time required to mow one acre	
				Man hours	Horse hours
Less than 2	11	1.54	28.5	1.3	2 6
2-4.9	21	3 35	37.6	1.2	2 4
5-9 9	11	7.08	46.2	1.0	2.0
10 or more	7	15.73	61.4	1 0	2.0
Total	50	....	....	....	....
Average	....	5.50	40.8	1.1	2.2

Size of fields is less important in mowing (table 6) than in most other farm operations. One reason for this difference is that large fields usually are not mowed as one field but are mowed in two or more parts.

TABLE 7. RELATION OF SIZE OF FIELDS TO LABOR REQUIRED TO CUT AND BIND AN ACRE OF CORN WITH A CORN HARVESTER

Size of fields (acres)	Number of fields	Average size of fields (acres)	Average length of fields (rods)	Time required to bind one acre of corn	
				Man hours	Horse hours
Less than 5	7	3.63	43.4	2.3	6.6
5-9 9	9	7.12	48 7	2.1	5.4
10 or more	6	14.40	70.1	1.8	5.5
Total	22	....	....	....	....
Average	....	8.0	52.9	2.0	5.6

The cost-account data on which these studies were based could not be used for studying the effect of this factor on dragging and cultivating. However, there is every reason to suppose that, in these operations as in the others, larger fields give more effective use of labor. The saving of labor by large fields in any one operation may not be important, but the aggregate saving in several operations is worthy of careful consideration.

TABLE 8. RELATION OF SIZE OF FIELDS TO LABOR REQUIRED TO CUT AND BIND AN ACRE OF GRAIN WITH A GRAIN HARVESTER

Size of fields (acres)	Number of fields	Average size of fields (acres)	Average length of fields (rods)	Time required to bind one acre of grain	
				Man hours	Horse hours
Less than 2	10	1.17	22.2	2.22	5 77
2–4 9	30	3.54	37 2	1.61	4.22
5–9 9	34	7.09	45.7	1.33	3.81
10–14 9	15	11.69	49.7	1.38	3.74
15 or more	18	20.47	77.8	1.23	3.66
Total	107	....	....	....	....
Average	... ...	8 44	47.1	1.34	3.87

Effect of size of fields on economy of fencing and of land

Fences around crop fields make more or less land untillable. With fields of a constant shape, the larger the field, the fewer rods of fence to the acre are required to inclose it. Therefore, with larger fields a smaller proportion of the area is occupied by fences. If a square field of 1 acre is fenced, about 50 rods of fence are required to inclose it; if a square field of 10 acres is fenced, only 16 rods of fence to the acre are required to inclose it; while only 8 rods of fence to the acre are required to inclose a square field of 40 acres. If the width of the land occupied by fences in the three fields were uniform, the amount of waste land to the acre would be twice as much in the 10-acre field as in the 40-acre field, and more than six times as much in the 1-acre field as in the 40-acre field.

A study was made of the relation of size of fields to economy of fencing and of land for the fenced crop-fields on the fifty-three New York farm All fields of a given size are included, regardless of shape. The resul are shown in table 9. In these results, the number of rods of fence to t acre includes all of the fence around each field. When a fence serves two fields, the amount of fence necessary for each would be correspondi reduced.

The importance of the effect of size of fields on land occupied by fences and on the amount of fencing depends on the value of the land, on the amount of crop land fenced, and on the cost of fence maintenance. If

the farm were divided into 2-acre fenced fields, about 4.5 per cent of the crop land would be occupied by fences; or, in other words, of every 100 acres of crop land, only 95.5 acres would be available for producing crops.

TABLE 9. RELATION OF SIZE OF FIELDS TO ECONOMY OF FENCING AND OF LAND IN CROP FIELDS COMPLETELY FENCED

Size of fields (acres)	Number of fields	Average size of fields (acres)	Rods of fence to the acre	Per cent of crop land occupied by fences
Less than 4	26	2.15	36 7	4.64
4–7 9	41	6.30	21.1	3.75
8–11.9	64	9 84	16.7	2.66
12–15.9	27	13 28	15.1	2.26
16–23.9	24	18 44	12.7	1.85
24 or more	12	38.33	9 0	1.12
Total	194	......	......	......
Average	....	11.37	15.1	2.29

Conclusions on effect of size of fields

The preceding studies show that large crop fields give greater economy of labor than do small fields. The effect of size of fields on labor, on any farm, depends on the number of horses driven to a team and on the crops grown, but it is important on every farm. The effect of size of fields on the economy of fencing and of land depends on the proportion of the crop area fenced, on the value of the land, and on the cost of fence maintenance, but it is important on most farms. For these reasons farmed fields should be as large as conditions will permit.

The size of the farm, the type of farming, and the length of the rotation or rotations followed, limit the size of fields on any farm. With the practice of more or less definite crop rotations, it is desirable to have as many fields as there are years in the rotation, and to have the fields of approximately equal size. With 100 acres of land available for general crops and a five-years rotation, the most desirable size of field would be 20 acres. This would give five 20-acre fields. On some farms, two distinct rotations are followed — a short rotation of more intensive crops on fields near the buildings, and a longer rotation of more extensive crops on the remoter fields.

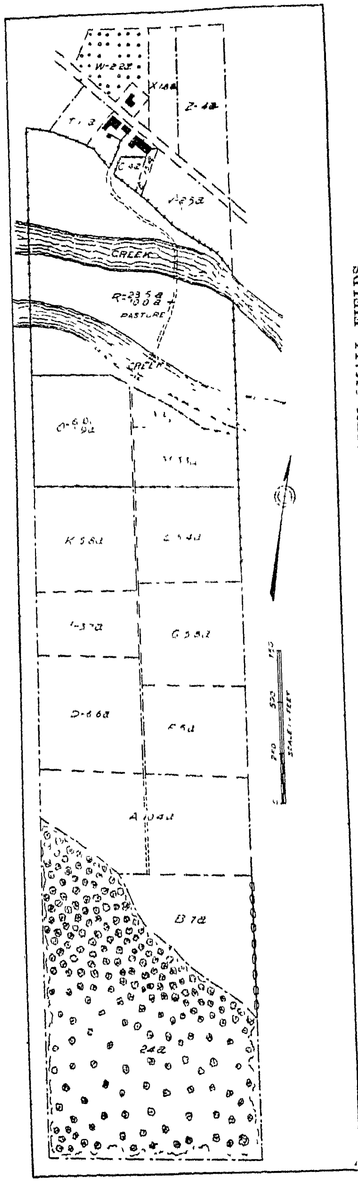


FIG. 78. A SMALL FARM DIVIDED INTO SIXTEEN SMALL FIELDS

There are no interior fences nor other obstacles to prevent the enlarging of the fields

A five-years rotation is followed.

Farm area, 122 acres
Average size of farmed fields, 4.4 acres
Average distance to farmed fields, 128 rods

Under these conditions a greater number of fields would be desirable, the number and size depending on the length of the rotations and the area of land available for crops. Where truck crops are grown, many fields of small to medium size are necessary.

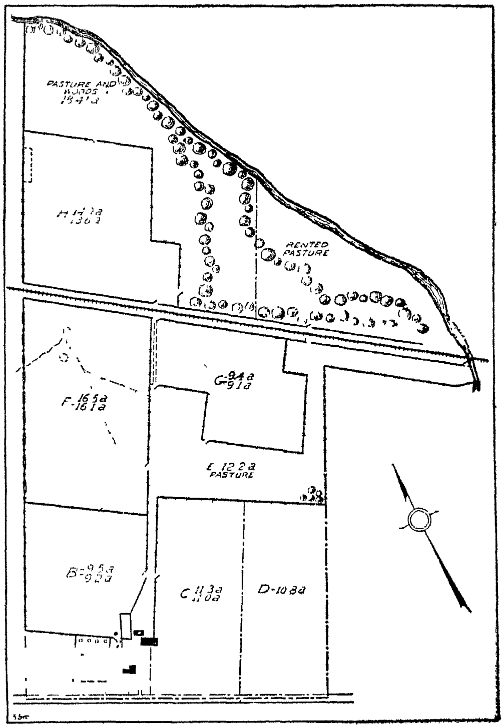


FIG. 79. A FARM HAVING ABOUT THE SAME CROP AREA AS THE FARM SHOWN IN FIGURE 78, BUT DIVIDED INTO SEVEN FIELDS OF GOOD SIZE AND SHAPE

A five- or six-years rotation is followed, the remainder of the land being used for minor crops There are no road fences and the fields are farmed to the edge of the road

Farm area, 108 8 acres
Average size of farmed fields, 10 3 acres
Average distance to farmed fields, 56 rods

Physical features, such as shape of farm, differences in soil or drainage, streams, and swamps, often make it impossible to have all the farmed fields as large as the crop area and the rotation would make desirable. In such cases two, or even more, fields may be farmed together as one course of the rotation.

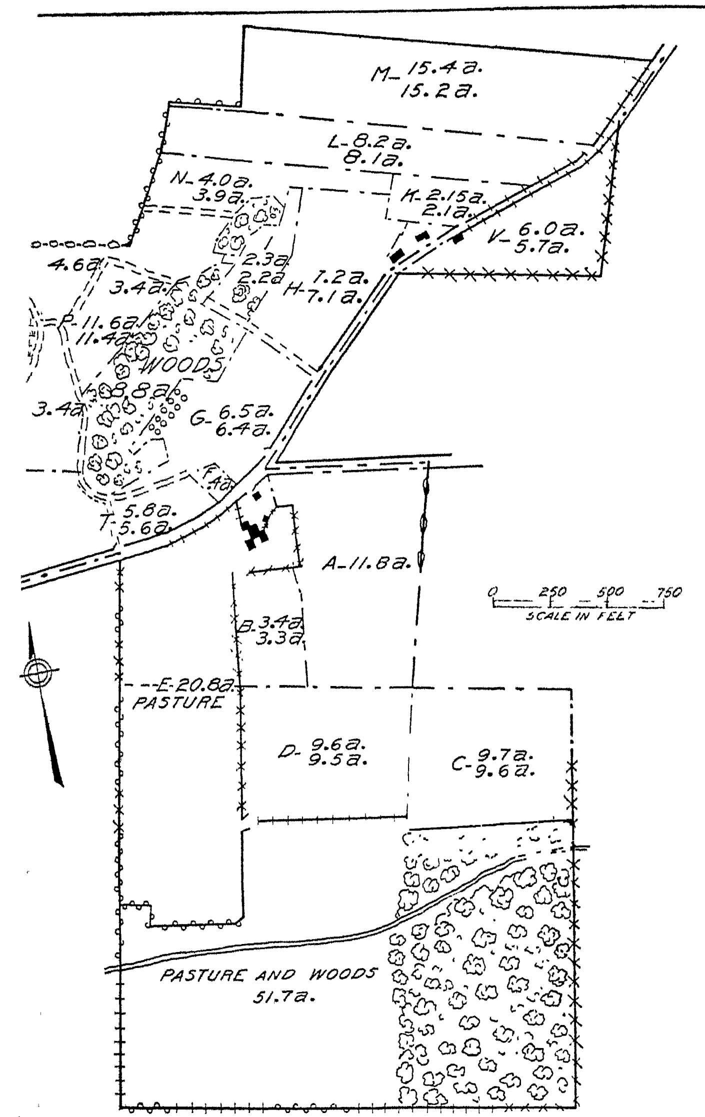


FIG. 80. A FARM OF MODERATE SIZE DIVIDED INTO NINETEEN FIELDS, MOSTLY OF SMALL SIZE

The patch of woods surrounded by crop land occupies an untillable rock outcrop

Farm area, 191 7 acres
Average size of farmed fields, 5.7 acres
Average distance to farmed fields, 77 rods

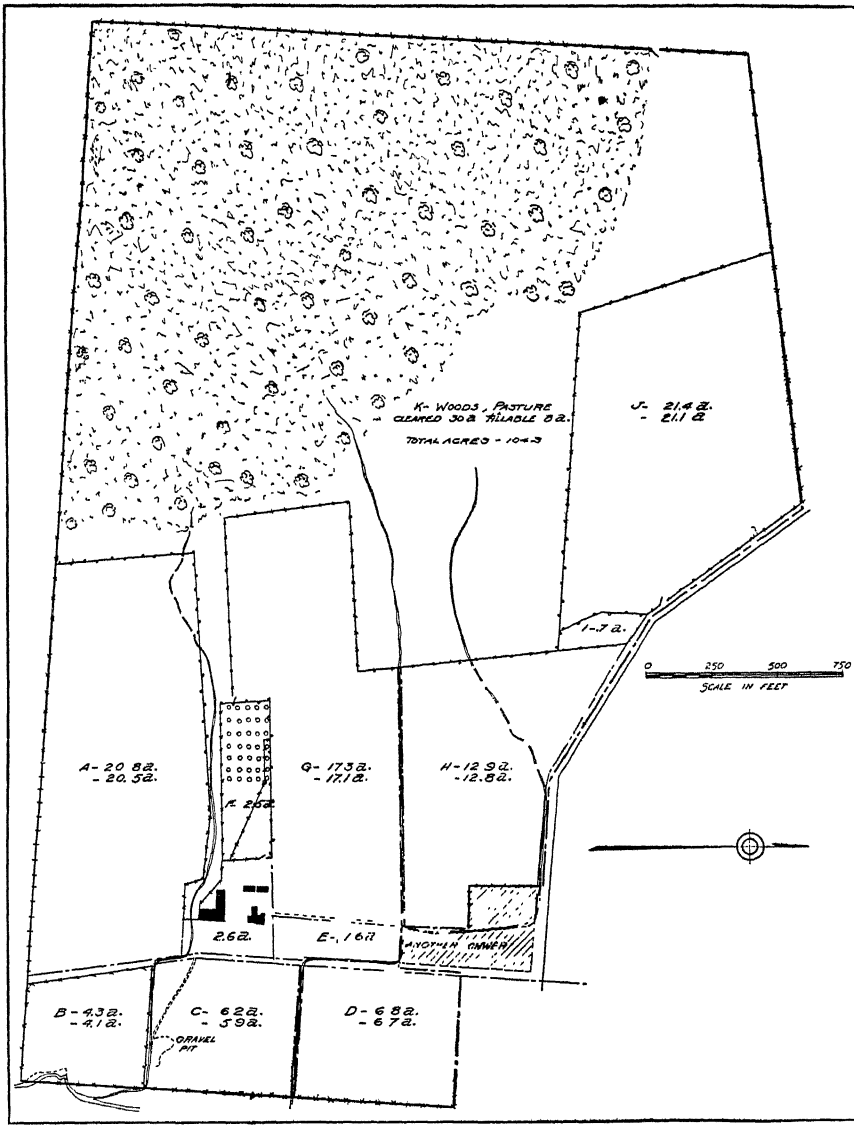


FIG. 81. ANOTHER FARM OF THE SAME SIZE AS THAT SHOWN IN FIGURE 80, BUT DIVIDED INTO FOUR LARGE FIELDS FOR THE MAIN ROTATION (CORN, OATS, HAY TWO YEARS) AND FOUR SMALL FIELDS FOR BEETS, POTATOES, ALFALFA, AND OTHER MINOR CROPS

Farm area, 205.7 acres
Average size of farmed fields, 11 2 acres
Average distance to farmed fields, 53 rods

Farm fields are often smaller than is either necessary or desirable. On many farms, little attention has been paid to the enlarging of fields to permit more effective use of labor and machinery. The crop area is still cut up into small fields by the original stone rows or fences built when the land was cleared, because it is easier in any one year to farm around

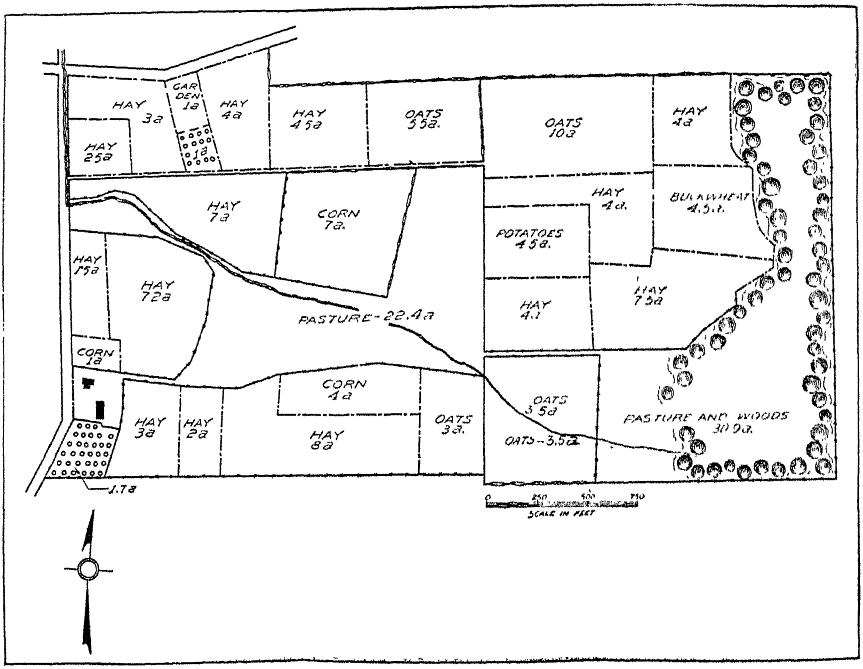


FIG. 82. AN EXAMPLE OF PATCH FARMING

The crop land was farmed in twenty-four fields averaging 4.5 acres each. There were three patches of corn, five of oats, one of potatoes, one of buckwheat, and fourteen of hay on this farm in 1914. There were few obstacles to prevent the enlarging of the fields, and this has been done since the map was made

Farm area, 212 acres
Average size of farmed fields, 4.5 acres

these obstructions than to remove them. Furthermore, there are constant forces tending toward smaller fields. Perhaps the seeding on part of a meadow fails. The patch is plowed up, and thereafter is often farmed as a separate field. A drought may prevent planting the entire field to the desired crop. The farms included in this investigation average slightly less than 100 acres of general crop land (other than fruit) to the farm,

divided into eleven fields averaging 9 acres each. On most of these farms a three- to six-years rotation is followed. The fields are smaller and more numerous than is either necessary or desirable. Very often, several small

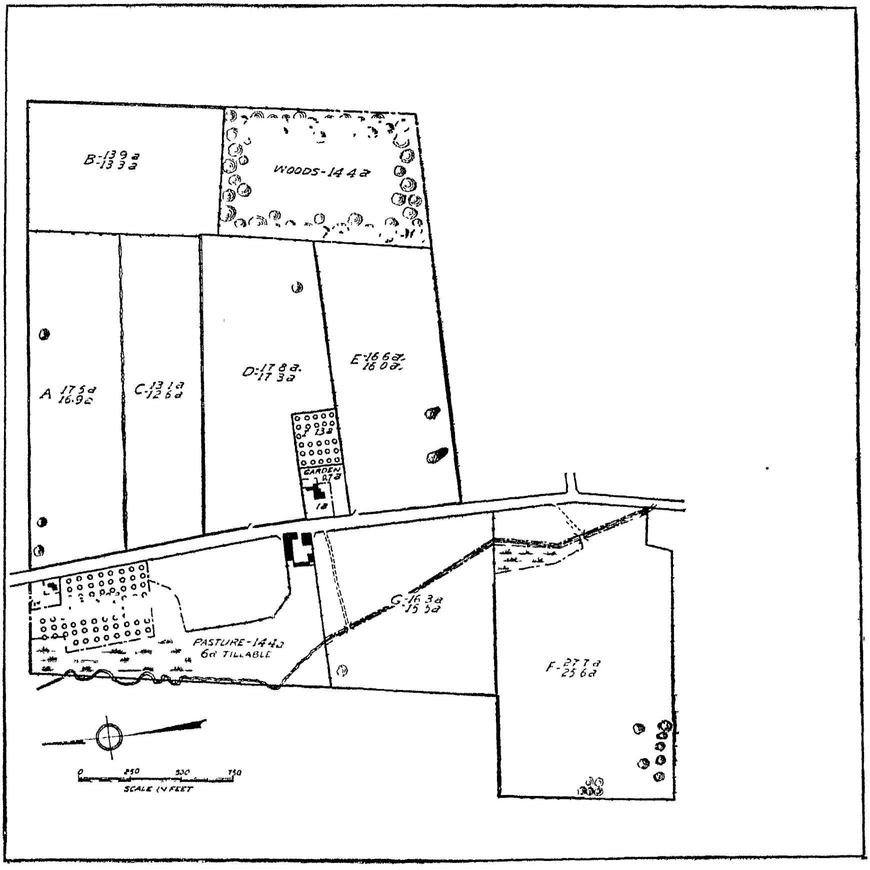


FIG. 83. A FARM SMALLER IN TOTAL AREA BUT A LITTLE LARGER IN CROP AREA THAN THAT SHOWN IN FIGURE 82

The fields are large and most of them are of good shape

Farm area, 163 acres
Average size of fa[illegible] fields, 16 7 acres
Average distance [illegible], 43 rods

patches of a given crop are grown on one farm without any real reason. Much time that is lost in farming these scattered patches could be saved by bringing them together into one field.

There are many factors that make difficult or even impossible the task of enlarging farm fields to the size most desirable. On some farms, physi-

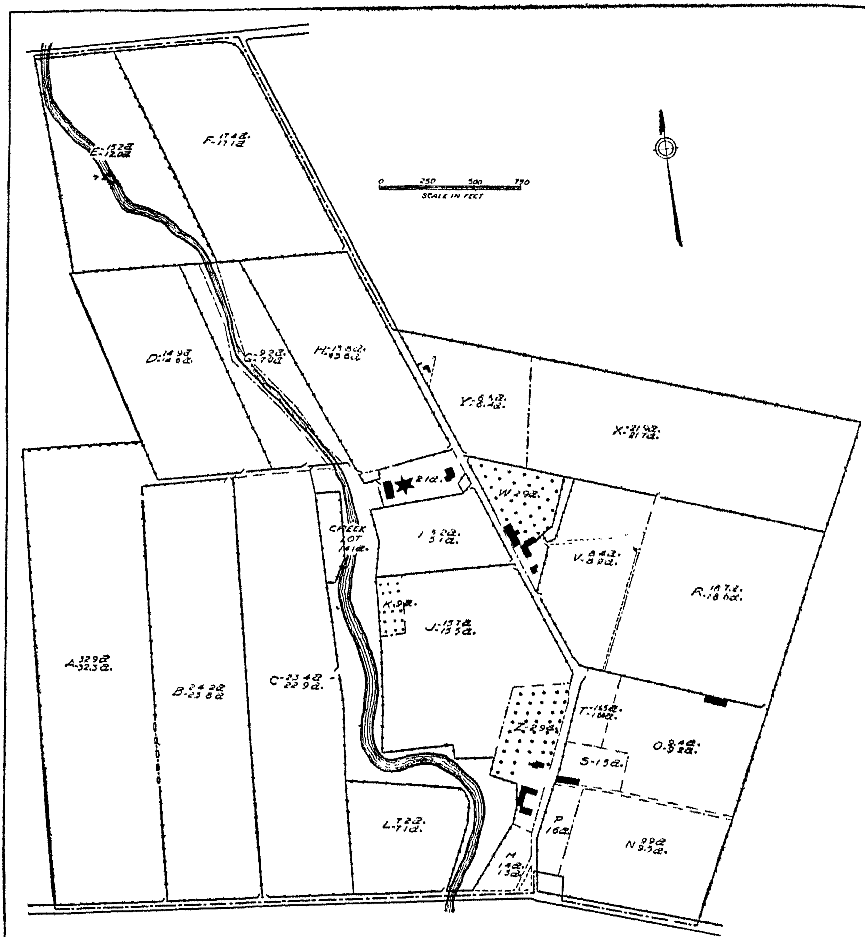


FIG. 84. A LARGE FARM DIVIDED INTO TWENTY-ONE CROP FIELDS AVERAGING 12 ACRES EACH

Farm area, 293 1 acres
Average size of farmed fields, 12 acres
Average distance to farmed fields, 70 rods

cal features will partially prevent the combining of small fields into larger fields. On other farms, the prospective savings with larger fields do not justify the expense necessary to make them. On many farms, however,

the readjustments can be made very easily. In any case the problem is worthy of careful consideration.

Maps of several New York farms of various sizes, which present striking contrasts in the average size of farmed fields, are shown in figures 78 to 85 (pages 416 to 423).

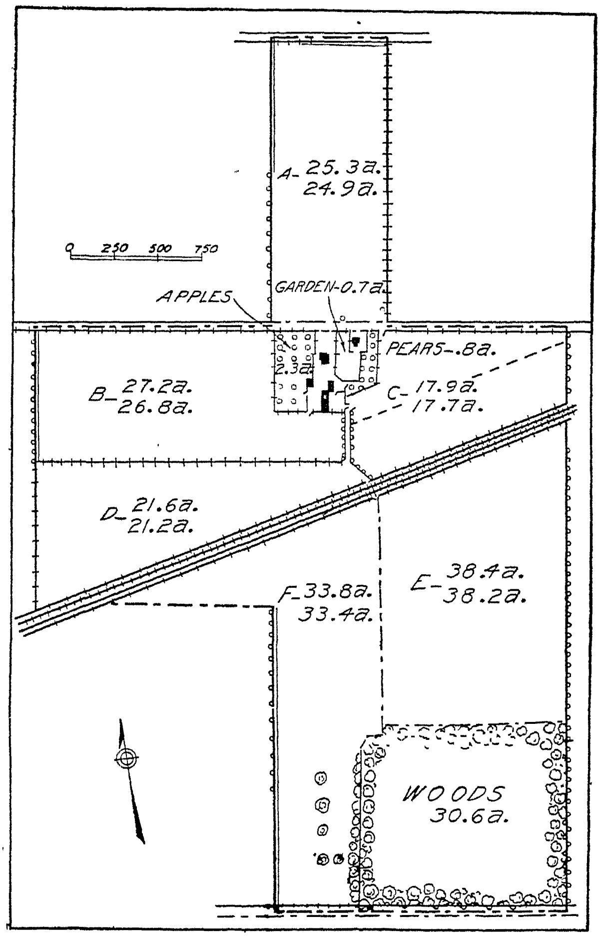


FIG. 85. A SMALLER FARM THAN THAT SHOWN IN FIGURE 84, BUT WITH ITS SIX CROP FIELDS AVERAGING 27 ACRES EACH

Farm area, 204.4 acres
Average size of farmed fields, 27 acres
Average distance to farmed fields, 30 rods

SHAPE OF FIELDS

The shape of farm fields likewise has an important effect on the economical use of labor, fencing, and land.

Effect of shape of fields on labor

It is a fact commonly accepted that more time to the acre is required for performing farm operations in fields of irregular shape than in fields of regular shape. In order to determine the effect of this factor on the time required for plowing an acre, E. L. Baker kept a careful record[2] of the time required to plow fields of different shapes. The dimensions and shapes of the fields are indicated in figure 86.

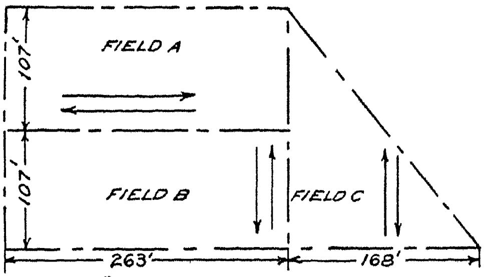


FIG. 86. DIMENSIONS AND MANNER OF PLOWING OF FIELDS OF VARIOUS SHAPES

All conditions were made as uniform as possible. Small areas were taken in order to secure uniformity of soil and moisture conditions. All the fields were plowed by the same man and team. A part of a forenoon and a part of an afternoon were spent in plowing each field in order to obviate any difference in freshness of the team. A Wiard walking plow was used, turning a furrow 14 inches wide and 8 inches deep.

Field A was plowed lengthwise, as indicated by the arrows in the diagram. Field B, equal in size to field A, was plowed the short way. Field C was triangular in shape and was plowed the long way. The time required to plow each field and the rate of plowing to the acre are shown in table 10.

Altho fields A and B are of the same size, about 14 per cent more time was required to plow field B. This was due to the shorter furrows and more frequent turns in field B, which wasted considerable time. It required 22 per cent more time to plow the triangular field C than to plow field A. Altho the average length of furrows in fields B and C are the same, seven per cent more time was required to plow field C. The

[2] Economical effects of shape and size of fields upon agriculture. By E. L. Baker. Thesis, Department of Agricultural Economics and Farm Management, Cornell University. (Unpublished.) 1909.

steadily diminishing length of furrows in field C worried the horses more than did the short furrows of the same average length in field B.

TABLE 10. RELATION OF SHAPE OF FIELDS TO TIME REQUIRED TO PLOW AN ACRE

Field	Size of field (square feet)	Time required to plow field	Time required to plow one acre at same rate
A	28,141	218 min.	5 hrs. 37 min.
B	28,141	248 min.	6 hrs. 24 min.
C	17,976	170 min.	6 hrs. 52 min.

Any irregular shape for a farm field is undesirable. The larger the proportion of the area of a field in short rows, the worse is the shape of the field and the greater is the amount of labor wasted in farming it (fig. 87).

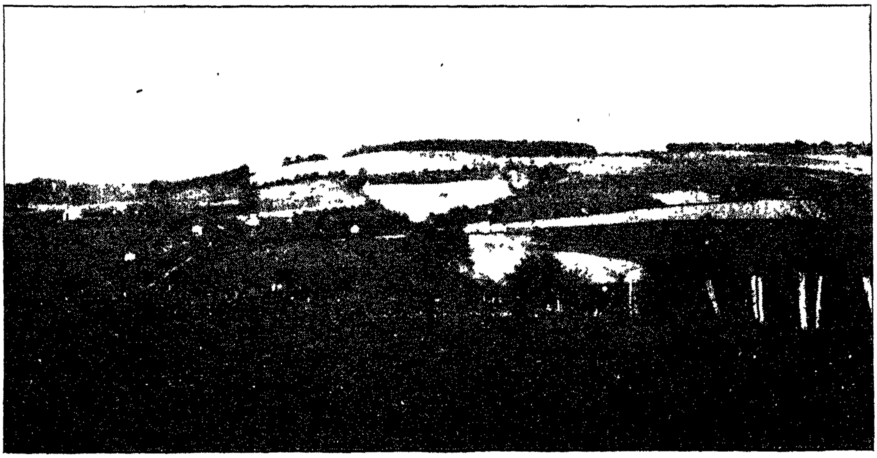


FIG. 87. SMALL, IRREGULAR FIELDS, WHICH WASTE LABOR AND LAND AND ARE EXPENSIVE TO FENCE

Triangular fields have the largest proportion of short rows and are the most wasteful of labor. Square fields are bad if they are small, because with mowing or other operations that require going around the field the bouts become extremely short near the finish; if they are large enough to be cut in two for these operations, however, they are satisfactory. For

fields of moderate size, the oblong shape is the best. The most desirable proportions depend somewhat on the size of the field and on the number of operations to be performed crosswise of the field. Oblong fields from one and one-half to three times as long as their width are usually satisfactory (fig. 88). Small fields should be proportionally longer than large fields, in order to provide longer rows. Fields long in proportion to their width are very convenient for plowing and other operations performed lengthwise, but are inconvenient for dragging or cultivating crosswise. They

FIG. 88. A LARGE RECTANGULAR FIELD ADAPTED TO ECONOMICAL OPERATION
This field is 100 rods long and 40 rods wide

also require more travel with an empty wagon. In New York State little cultivating is done crosswise, and hence this drawback is not important. When a tractor is used, the length of the field is the most important consideration.

The importance of the effect of shape of field on labor varies inversely with the size of the field. The smaller the field, the more important is its shape; the larger the field, the less important shape becomes. Even the short rows in a large field may be longer than the longest rows in a small field. A dozen short rows in a 2-acre field may mean a considerable proportion of time wasted, while the effect of the same number of short rows on the labor necessary to farm a 20-acre field would be small.

The importance of the effect of shape of field on labor depends also on the operations to be performed, and hence on the crops grown. The more intensive crops require a greater number of operations, and therefore a

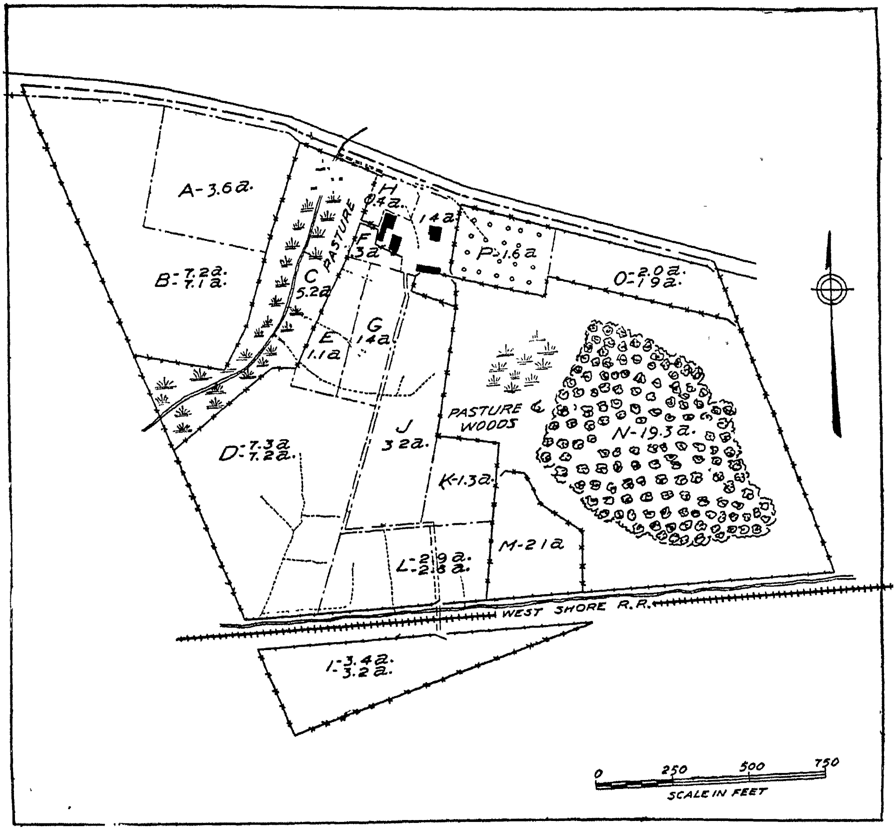


FIG. 89. A SMALL FARM IN CENTRAL NEW YORK HAVING BADLY SHAPED FIELDS

Efficient use of labor is impossible in fields like these
Farm area, 65.4 acres
Average size of farmed fields, 2 7 acres
Average distance to farmed fields, 44 rods

larger amount of time is wasted by growing such crops in irregular fields. With extensive crops such as hay or alfalfa, the waste of time in irregular fields is less important. This fact is recognized by farmers, and very badly shaped fields are usually kept in hay as much of the time as possible.

Effect of shape of fields on economy of fencing and of land

Square fields require the fewest rods of fence to the acre for a given size. A square field of 10 acres would require 160 rods of fence to inclose it. A rectangular field 80 by 20 rods would include the same area but would require 200 rods of fence. With the annual cost of fence maintenance at

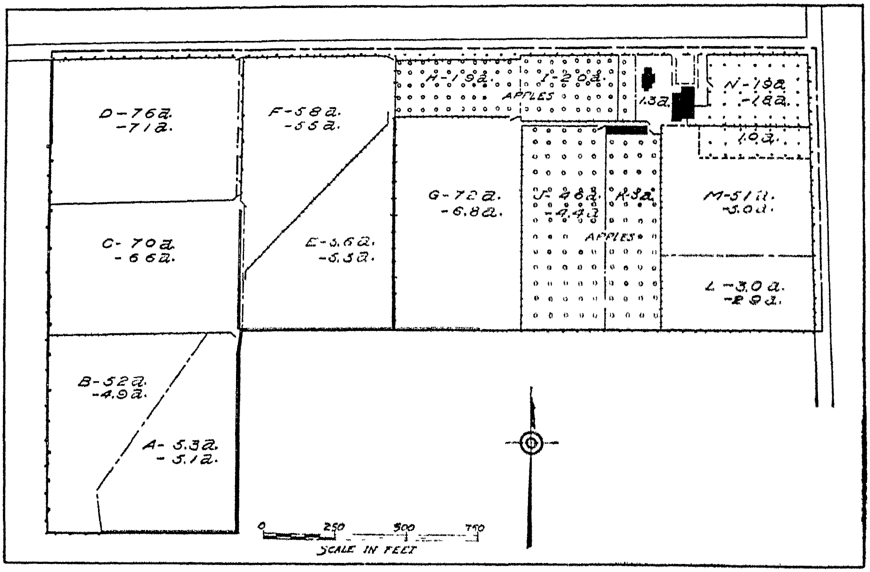


FIG. 90. A SMALL FARM IN WESTERN NEW YORK HAVING SOME WELL-SHAPED AND SOME BADLY SHAPED FIELDS

Fields A and E are hilly, and are therefore farmed separately. The unnecessary fence between fields E and F makes it impossible to farm into the sharp corner of either field. Wide fence rows, full of stone and brush, occupy 5 per cent of the crop land of this farm. Land is worth $125 an acre

Farm area, 69 acres
Average size of farmed fields, 4.5 acres
Average distance to farmed fields, 79 rods

6 cents a rod, it would cost $2.40 a year more to keep the rectangular field fenced.

Conclusions on effect of shape of fields

For the field of ordinary size, the oblong shape permits the most efficient use of labor, while the square shape is the most economical of fencing and of land. For pastures, therefore, the most economical shape is square, because this provides the shortest line of fence and only four corner posts.

Saving labor is usually more important than saving land and fencing, and hence oblong shapes are the most desirable for crop fields of moderate size. Very large crop fields may be square to save fencing, and yet be long enough to permit of efficient use of labor. Irregular shapes should be avoided when this is possible without too great expense.

The shape of farm fields has been affected by topography, drainage, streams, soil, and other natural factors, as well as by the manner in which

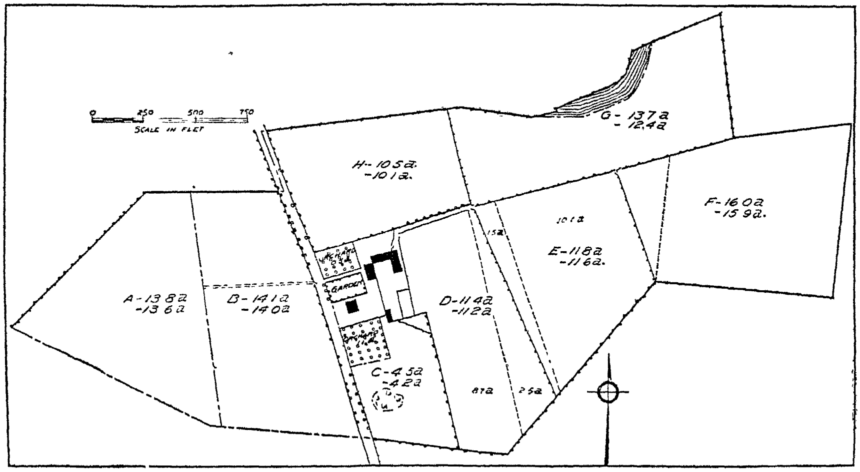


FIG. 91. A CROOKED FARM IN SOUTHERN NEW YORK WITH IRREGULAR FIELDS

The crooked board fence between fields D and E makes 2.5 acres of short rows in field D and 1.5 acres of short rows in field E. By straightening the fence all the short rows in field E and most of those in field D could be eliminated. The crooked outline of the farm is due to the way in which this section was surveyed

Farm area, 101.5 acres
Average size of farmed fields, 11.6 acres
Average distance to farmed fields, 48 rods

the farms were cleared. On the farms included in this investigation 42 per cent of the crop land was in fields that were approximately oblong in shape, 8 per cent was in square fields, and 50 per cent was in irregular fields. The proportion of the crop area in badly-shaped fields varies in different agricultural regions of the State, being 41 per cent on twenty-four western New York farms included in this study, 52 per cent on eleven southern New York farms, 57 per cent on twelve central New York farms, and 75 per cent on four southeastern New York farms. The worst-shaped fields are found in that part of the State which was

settled first. Fortunately, in this region a large part of the crop area is in hay, and the shape of the fields is therefore less important than if a larger proportion of intensive crops were grown. The best-shaped fields are found

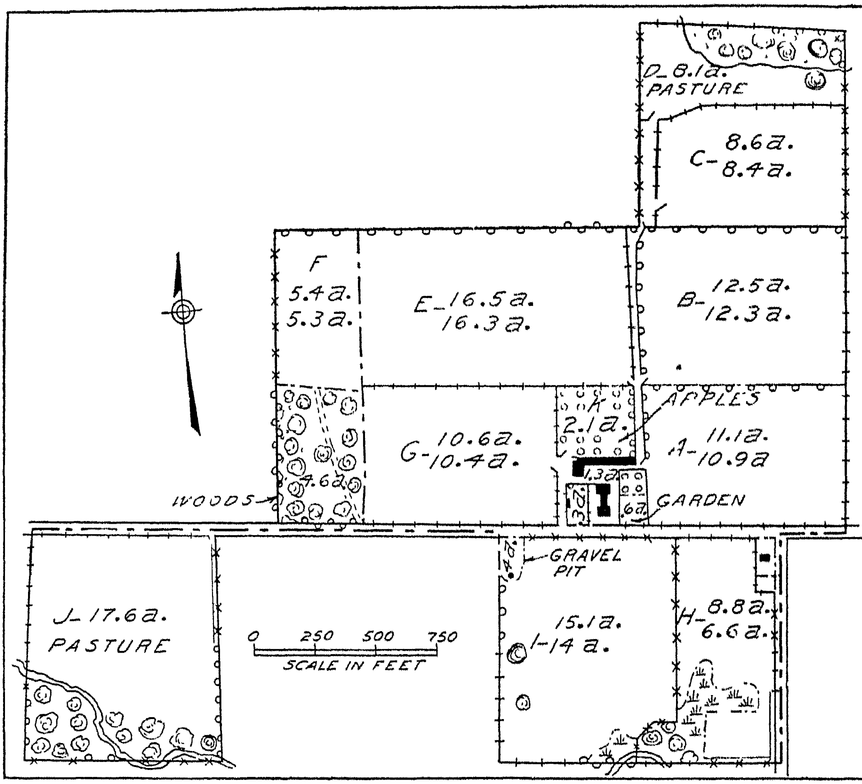


FIG. 92. A GOOD FARM LAYOUT IN CENTRAL NEW YORK

Most of the fields are of good size and shape A four- or five-years rotation is followed. Fields A and C, B and G, H and I, and E and F have been farmed together, each pair of fields making up a course in the rotation. There are some unnecessary fences which could easily be removed

Farm area, 126.3 acres
Average size of farmed fields, 10.5 acres
Average distance to farmed fields, 32 rods

in that part of the State which was settled last, the western part. Even in this region, however, there is considerable opportunity for improvement.

In some cases the shape of the fields is the result of natural features, and rearrangement to secure fields of better shape is impossible. In

other cases the cost of improving the shape of the fields would be greater than any possible saving to be made. In many cases such improvements can be made easily and at reasonable expense. Before undertaking any

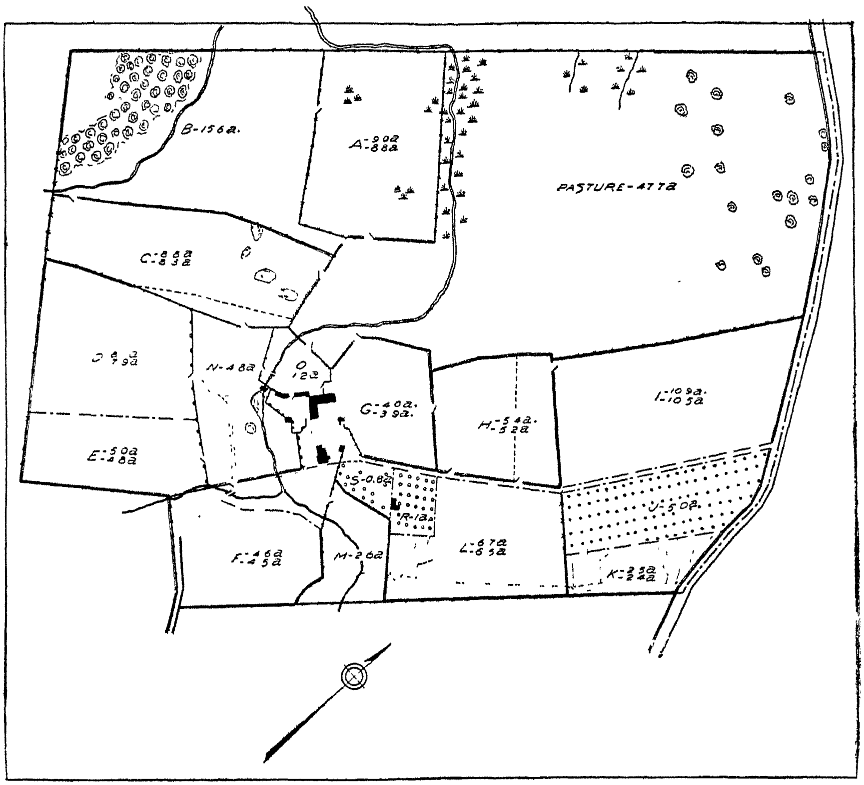


FIG. 93. LAYOUT OF A FARM IN SOUTHEASTERN NEW YORK

The irregularly shaped fields are bounded by stone fences which make rearrangement difficult. Much time is wasted owing to the small, irregular fields in this region

Farm area, 150 acres
Average size of farmed fields, 6 2 acres
Average distance to farmed fields, 47 rods

rearrangement, the probable savings and costs should be given careful consideration.

Plans of farms illustrating desirable and undesirable shapes of fields are shown in figures 89 to 95 (pages 427 to 433).

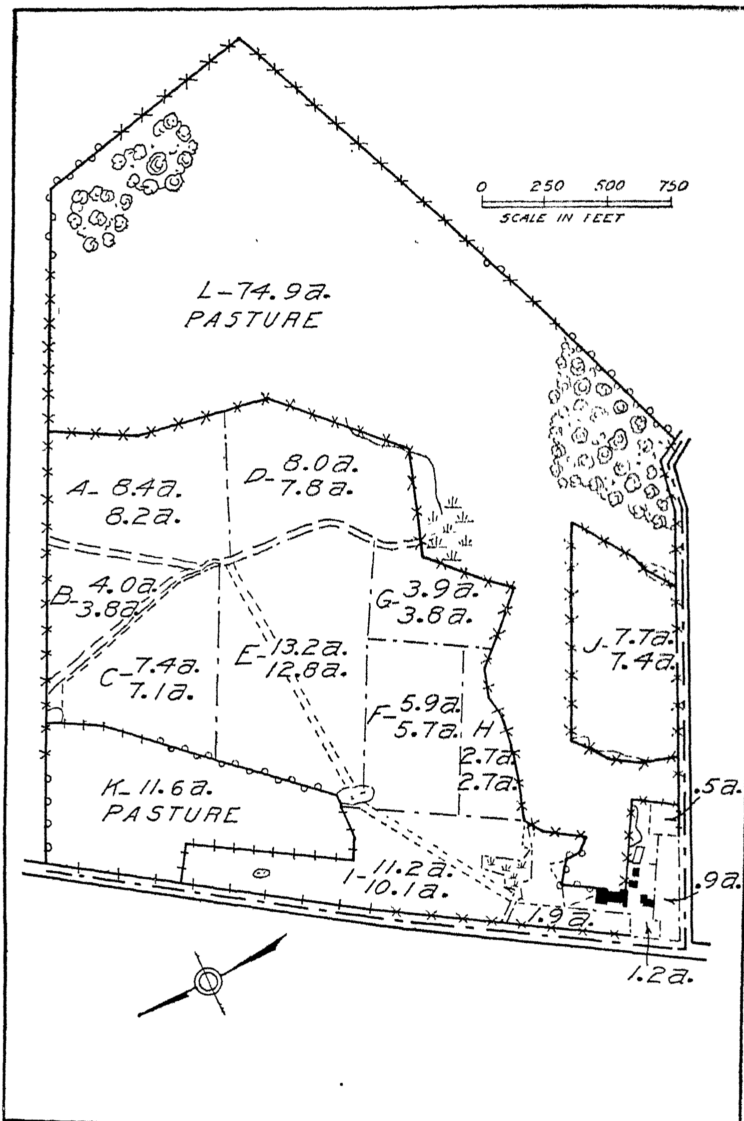


FIG. 94. A FARM LAYOUT IN NORTHERN NEW YORK

By tiling the open ditches the size and shape of these fields could be greatly improved. Some improvement could be made without any expense

Farm area, 164.5 acres
Average size of farmed fields, 6.9 acres
Average distance to farmed fields, 96 rods

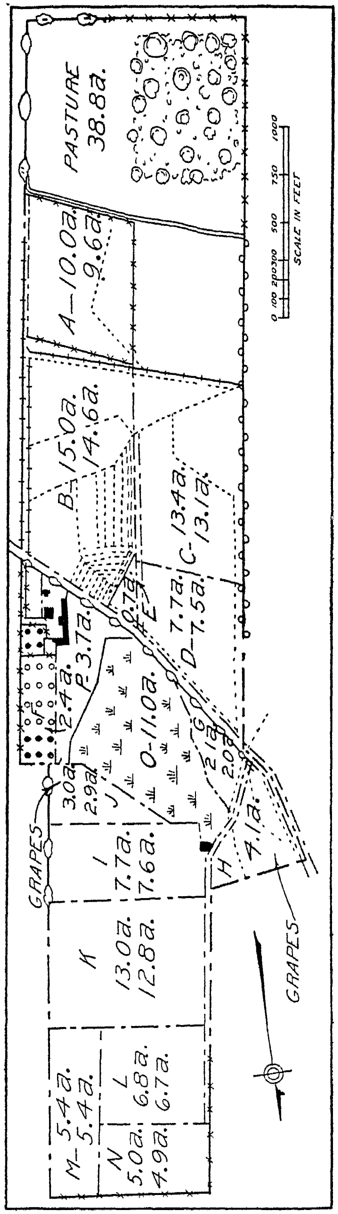


FIG. 95. PLAN OF A SOUTHWESTERN NEW YORK FARM

Farm area, 154 acres
Average size of farmed fields, 6 6 acres
Average distance to farmed fields, 92 rods]

LOCATION OF FIELDS WITH RESPECT TO BUILDINGS

Travel between barns and crop fields is not directly productive work. It is merely getting ready to do something. For this reason crop fields should be as readily accessible to the farmstead as possible.

The importance of the effect of this factor depends principally on the distance traveled and on the crops grown. For any given rotation of crops, the relative values of near-by and distant fields can be easily determined. With a five-years rotation of silage corn, oats, wheat, hay, the minimum number of trips to the acre, with average yields, would be about as follows:

	Man trips to the acre	Horse trips to the acre
Silage corn (including 10 loads of manure to the acre)	18.0	48.0
Oats	3.5	8.0
Wheat	3.5	8.0
Hay	2.1	3.8
Hay	2.1	3.8
Total above rotation	29.2	71.6
Annual average for above rotation (approximately)	6	14

If a field is a half mile distant from the barn, each round trip means a mile of travel, or at least 6 man miles and 14 horse miles of travel for each acre each year with the above rotation. This would require at least 2 hours of man time and 4.5 hours of horse time, which, at 30 cents an hour for man labor and 20 cents an hour for horse labor, would cost about \$1.50. Since \$1.50 is 6 per cent interest on \$25, it is evident that a field adjoining the barn would be worth about \$25 an acre more for general farming than an equally good field a half mile away under the conditions given.

The average distance between farmstead and fields depends chiefly on the size of the farm, the shape of the farm, the location of the farmstead with respect to the fields, and the size and arrangement of the fields. Other factors remaining constant, the larger the farm, the greater is the distance between farmstead and fields. This is one of the most important factors limiting the size of farms. If the size of a farm be indefinitely

increased, a point will be reached where the advantages of greater size are offset by the time lost in travel between buildings and fields. Any further increase in size then means a duplication of buildings.

The shape of the farm is nearly as important as the size in its effect on distance to fields. All long, narrow shapes are bad, since they mean that much of the land is farther from the buildings than it would be if the farm were more nearly square (fig. 96). Square or nearly square farms permit the most convenient arrangement of fields with respect to buildings (fig. 97). The ideal arrangement is to have half of the land on each side of the highway, with the buildings in the center of the farm (fig. 98). By this arrangement the travel to fields may be reduced to a minimum, and yet the advantages of living on the highway are retained. With any shape of farm and with the usual systems of farming, the most advantageous location for the buildings from the standpoint of labor efficiency is in the center of the crop land; but if this necessitates locating the buildings away from the highway, the disadvantages of the plan more than offset the saving of labor except in the case of very large farms. It is in some cases possible to put the house on the road by running a road thru the farm. When this can be done, the advantages to be gained much more than offset the value of the land lost. A location in the middle of the side of the farm on the road, is usually preferable to one in the corner nearest town.

It is usually desirable to have as many fields as possible corner on the farmstead. Often the average distance to the nearest corner of the crop fields can be reduced by enlarging the fields.

Because of the greater cost of farming distant fields, farmers tend to keep such fields in less intensive crops. In New York, fields too remote to be cultivated economically are kept in hay almost continuously. If the hay from such fields is to be sold, it is usually stacked or drawn to a near-by barn rather than to the main buildings. Fields too distant to be profitably cropped with hay are used for pasture. By such plans farmers have adjusted their practice to make the best of bad field arrangements.

On many farms, the remote fields are never manured and are continually getting poorer. Frequently such fields, too distant to be farmed economically by their owner, are directly across the road from a neighbor's house. The best way to put the buildings in the middle of the farm is to buy the land across the road when this is possible.

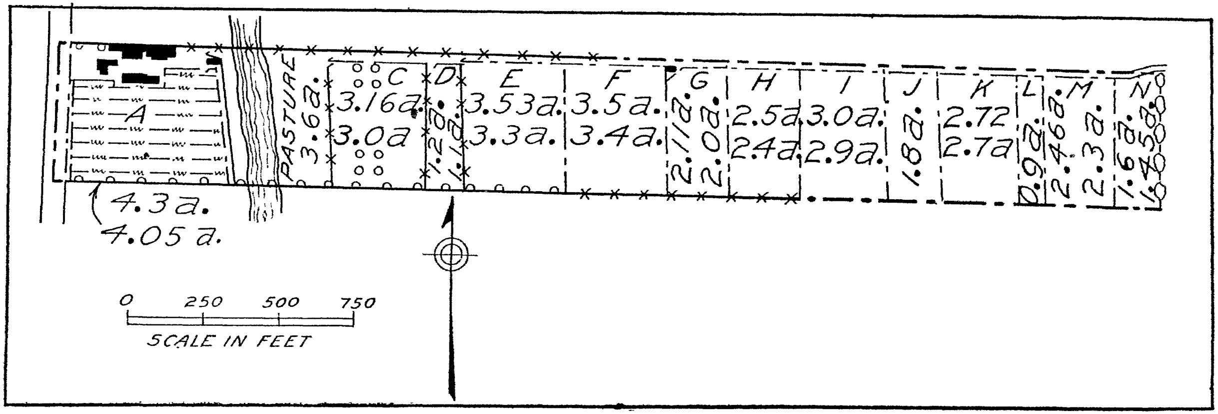


FIG. 96. PLAN OF A SMALL FARM SHOWING THE EFFECT OF SHAPE OF FARM ON DISTANCE TO FIELDS

The average distance to the nearest corners of the crop fields is 102 rods; the average distance to the centers of the crop fields is 116 rods. The average distance to the corners of the fields is greater than for the farm shown in figure 97, which is about ten times as large. The average distance to the centers of the crop fields is approximately the same for the two farms. For a well-laid-out square farm of the same size as the one shown in this figure, the average distance to the fields would be about 20 rods. With 1918 labor prices the saving of travel would make the square farm worth from $10 to $15 an acre more for general farming than an equally good farm with the arrangement shown here

Farm area, 37.9 acres
Average size of farmed fields, 2.4 acres
Average distance to farmed fields, 102 rods

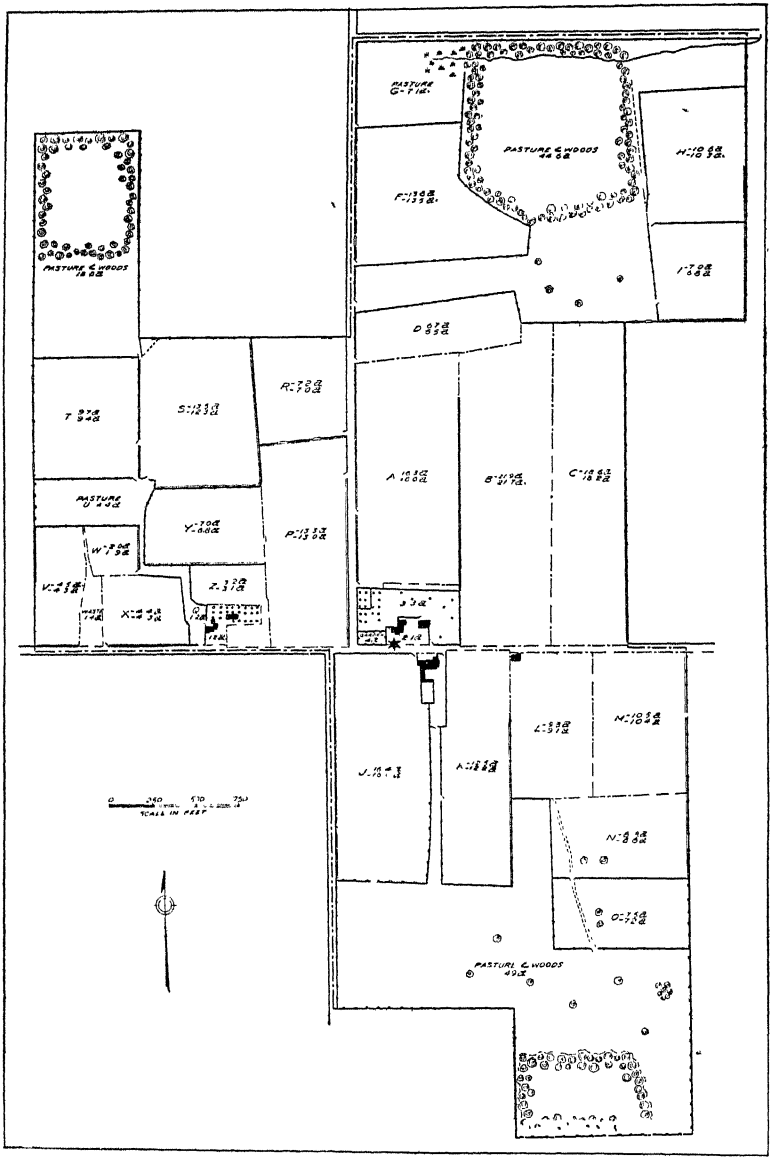


FIG. 97. A MUCH LARGER FARM THAN THAT SHOWN IN FIGURE 96, BUT WITH ABOUT THE SAME AVERAGE DISTANCE TO FIELDS

This farm is made up of four original farms. Many fields have been combined and enlarged and the process is still going on. Most of the fields are of good size and shape, but there is opportunity for further improvement

Farm area, 369.1 acres
Average size of farmed fields, 10.1 acres
Average distance to farmed fields, 86 rods

As has previously been pointed out, the inaccessibility of the fields on many farms is a natural consequence of the way in which farm layouts have developed. In the first place, little attention was paid to this consideration in laying out farms for settlement. Again, as farms have

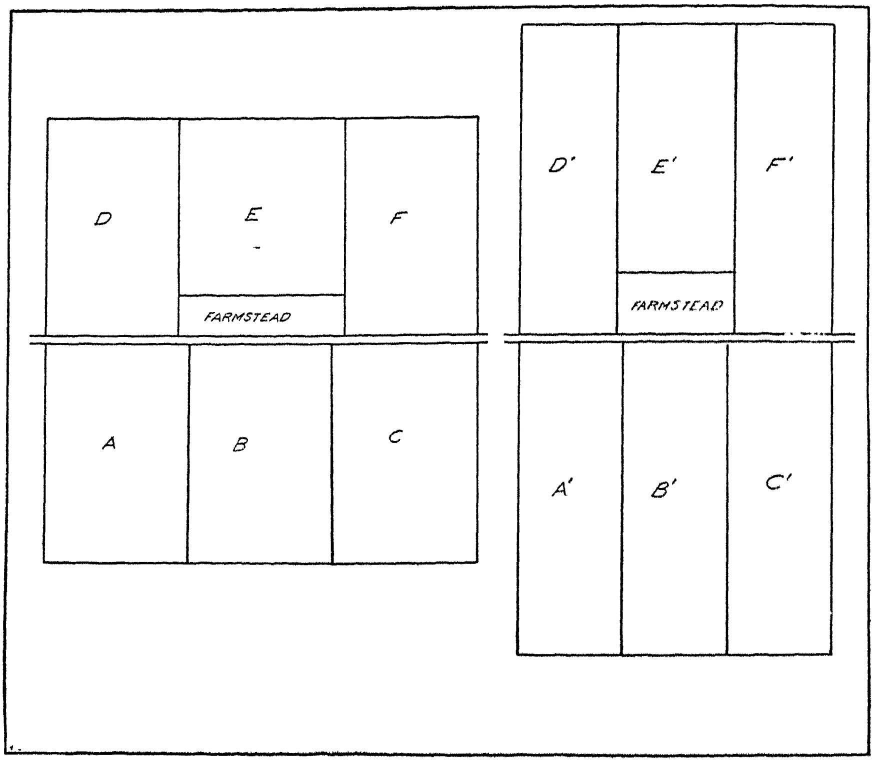


FIG. 98. TWO GOOD FARM LAYOUTS

If a 160-acre farm had either of these field arrangements, the average distance to fields would be less than 30 rods

been combined it has not always been possible to buy land adjacent to the farm already owned. Just as the layout of some farms has been improved by combination, that of others has been made worse. Within reasonable limits it is more important to have enough land than to have it convenient for working; or, in other words, the advantage of having more land may offset the disadvantages of an inconvenient location.

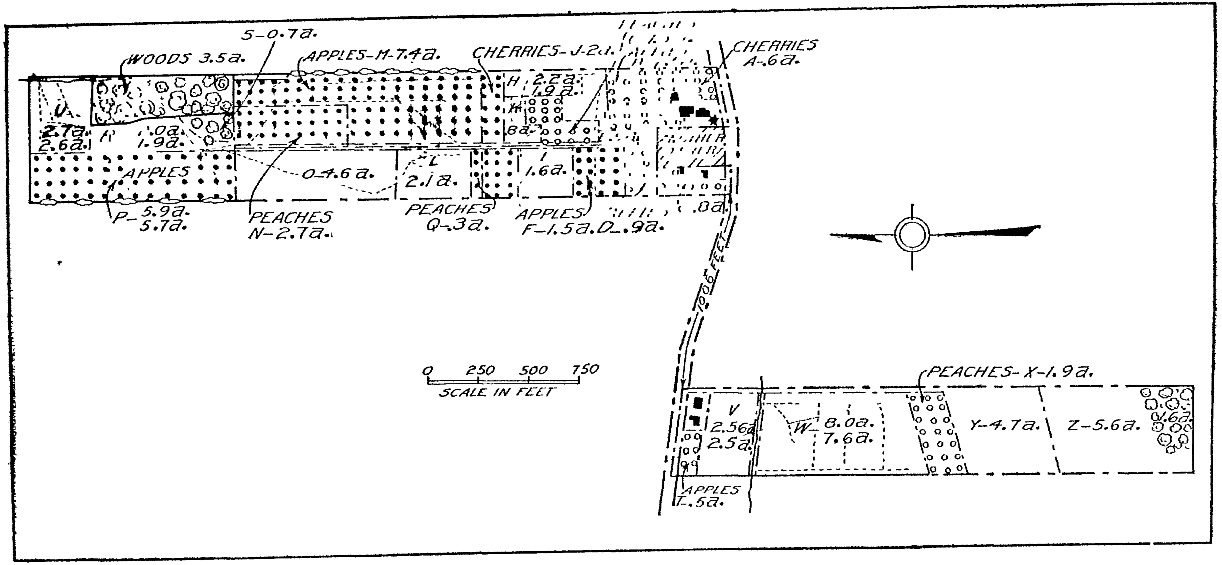


Fig. 99. PLAN OF A FARM IN THE INTENSIVE FRUIT BELT OF WESTERN NEW YORK

Such long, narrow farms mean much travel to and from fields. The field arrangement is made worse by the separation of the two parts of the farm. With the crops grown, and with 1918 labor prices, the distance of 60 rods between the two parts means a difference of $15 or $20 an acre in the value of the land for farming. The woodlot occupies tillable land too valuable for forestry purposes and is being cleared

Farm area, 74 8 acres
Average size of farmed fields, 2.6 acres
Average distance to farmed fields, 108 rods

It is probably worth while to see what an ideal arrangement is like, even tho such an ideal is unattainable in most cases. Realizing the importance of a convenient arrangement, one can plan an arrangement

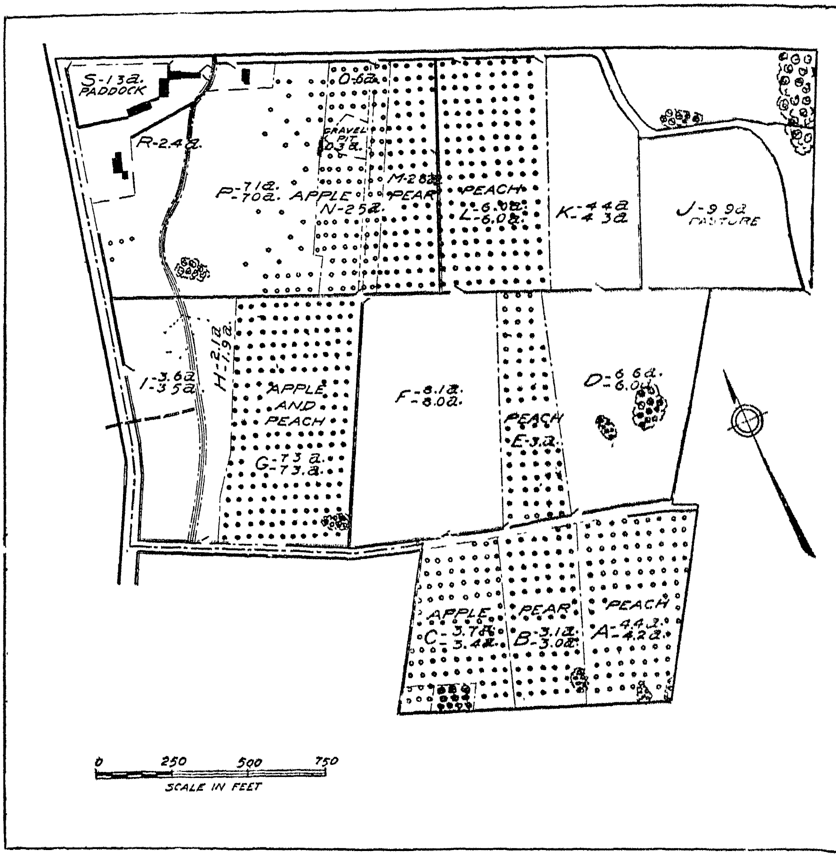


FIG. 100. A FARM PLAN WITH THE FARMSTEAD IN THE CORNER MOST DISTANT FROM THE FIELDS, THE WORST POSSIBLE ARRANGEMENT

This farm might be four times as large with no greater average distance to the fields. Such a plan has the principal disadvantages of a farm four times as large, with none of the advantages

Farm area, 83.6 acres
Average size of farmed fields, 4 1 acres
Average distance to farmed fields, 91 rods

for his farm which will approximate this ideal as closely as conditions permit. Farms illustrating good and poor arrangements with regard to this factor are shown in figures 99 to 111 (pages 439 to 451).

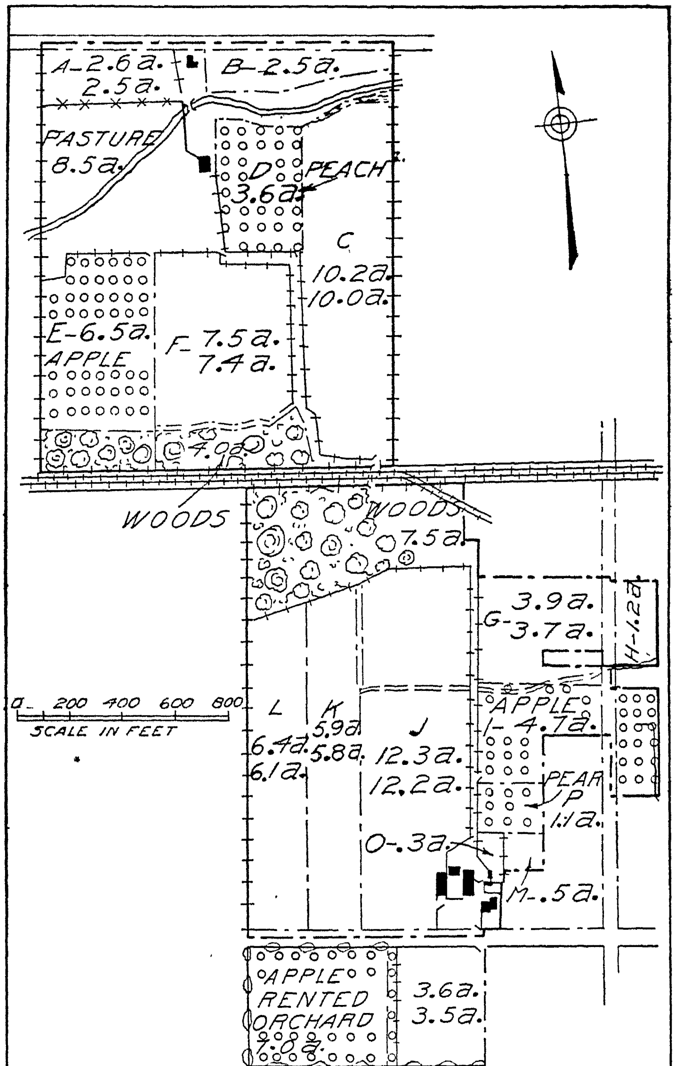


FIG. 101. A FRUIT FARM IN WESTERN NEW YORK

The part north of the railroad was originally a separate farm. The average distance to fields is as great as for many farms three or four times as large. The woodlot occupies tillable land which is too valuable for producing lumber

Farm area, 97.5 acres
Average size of farmed fields, 5.1 acres
Average distance to farmed fields, 90 rods

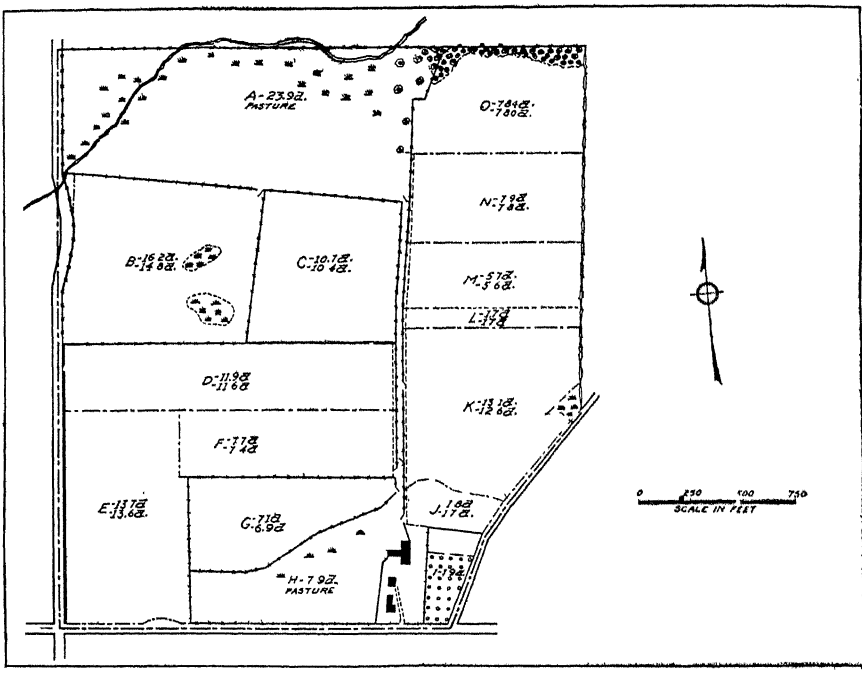


FIG. 102. A CENTRAL NEW YORK FARM

There are few interior fences or other barriers to prevent planning a satisfactory field arrangement for this farm

Farm area, 146.5 acres
Average size of farmed fields, 8.5 acres
Average distance to farmed fields, 70 rods

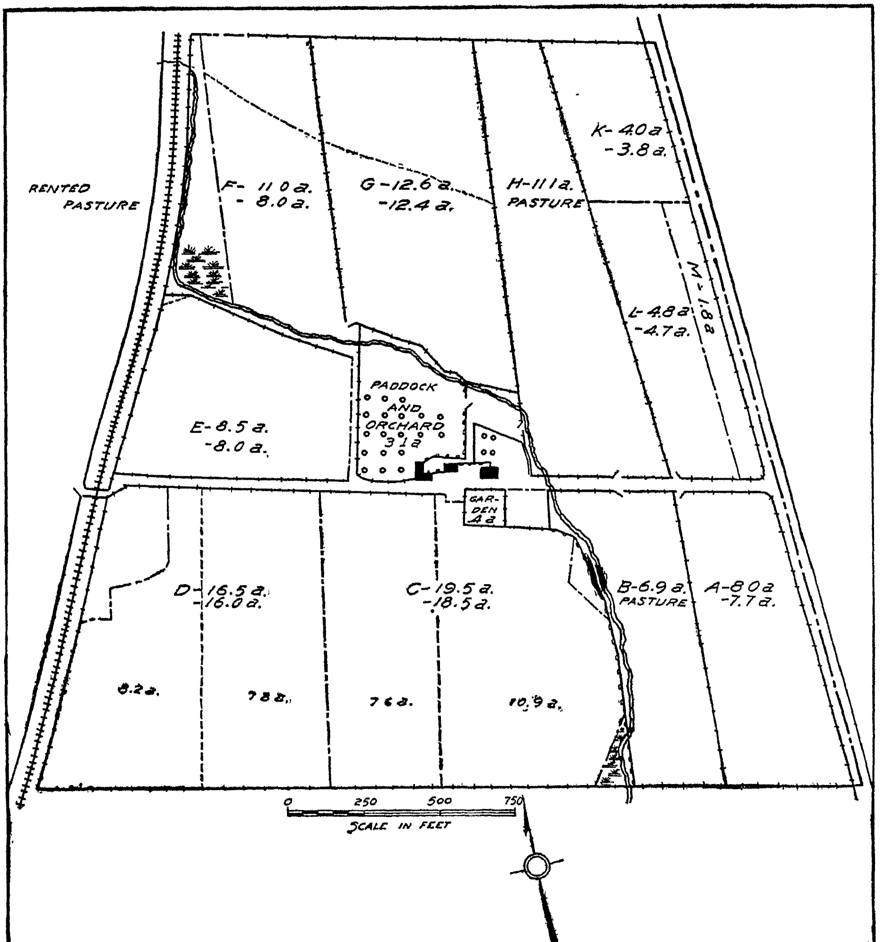


FIG. 103. A WESTERN NEW YORK FARM ON WHICH THE FARMSTEAD IS IN THE CENTER, AWAY FROM THE MAIN ROAD

The farmstead was originally located in field K There is no suitable building site along the highway because the highway is so much above the adjoining land. Under these conditions the present location is the best possible

Farm area, 114.5 acres
Average size of farmed fields, 9.1 acres
Average distance to farmed fields, 35 rods

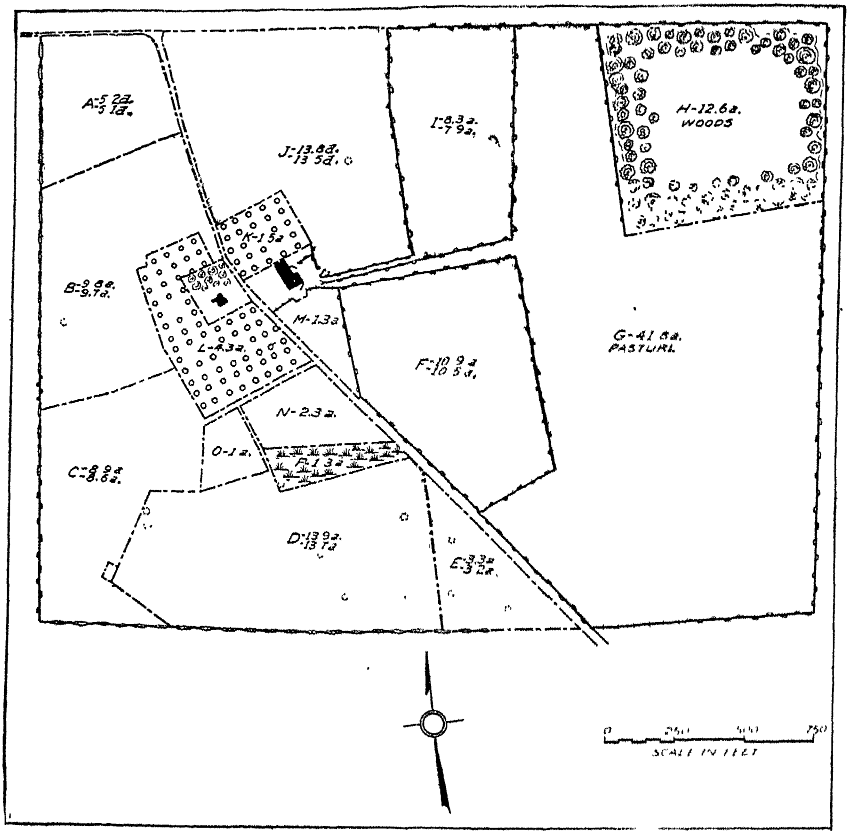


FIG. 104. A SOUTHERN NEW YORK FARM

The farmstead is situated in the center of the crop area, on the road. The average distance to fields is about one-fourth that on the farm shown in figure 99. The deed of this farm specifies 100 acres, more or less

Farm area, 144.5 acres
Average size of farmed fields, 6.3 acres
Average distance to farmed fields, 29 rods

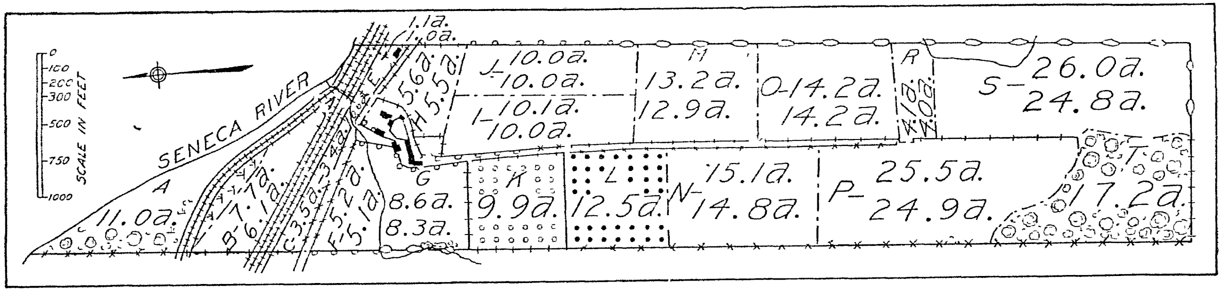


Fig. 105. A LARGE FARM WITH A POOR LAYOUT, IN CENTRAL NEW YORK

Land at the back end of this farm is too remote to be farmed economically by the owner, but is convenient to neighboring farmsteads In 1916 and 1917 a total of 50 acres of land lay fallow largely because it was too far away It is 240 rods from the horse barn to the nearest corner of field S, which, with man labor at 30 cents and horse labor at 20 cents an hour, would make that field worth from $35 to $40 an acre less for general farming than the field adjoining the barn. The farm is worth $100 an acre

Farm area, 210.3 acres
Average size of farmed fields, 10.5 acres
Average distance to farmed fields, 126 rods

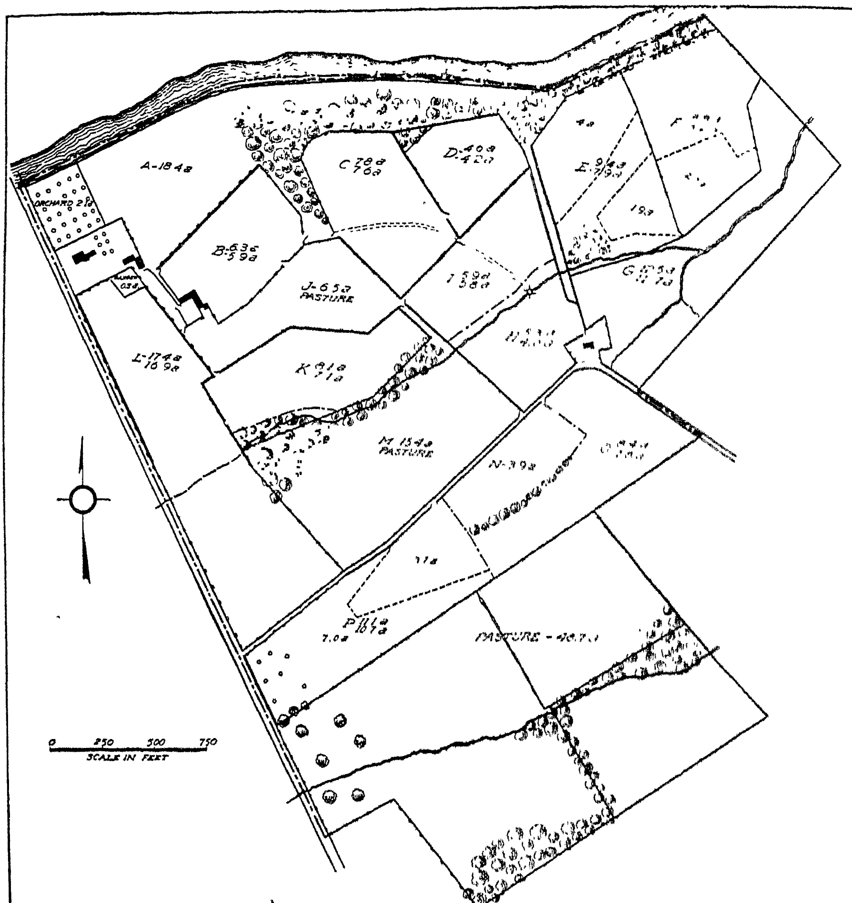


FIG. 106. ANOTHER POOR LAYOUT

The fields on this farm are small and irregular, and the farmstead is as far from the fields as possible. Many of the fence rows are so full of stone that it would not pay to clear them. The crooked fields are not due to topography, but largely to the manner of clearing

Farm area, 211.1 acres
Average size of farmed fields, 7.8 acres
Average distance to farmed fields, 113 rods

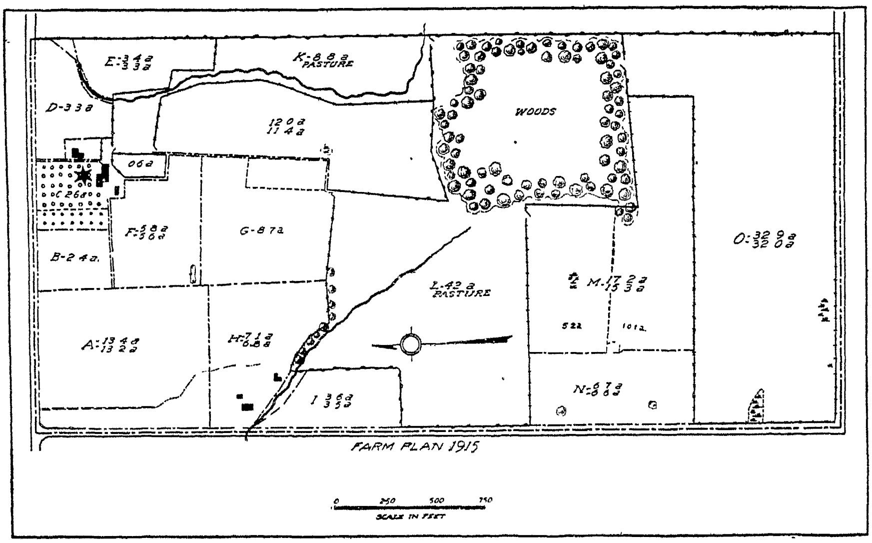


FIG. 107. A COMMON FARM LAYOUT IN WESTERN NEW YORK

Field O, at the back end of this farm, is directly across the road from the house of an adjoining farm. This field is 183 rods from the owner's barn, up hill, and is too far away to be cropped economically even tho it is the best field on the farm. It should be worth from $25 to $30 an acre more to the neighbor than to the present owner

Farm area, 175.8 acres
Average size of f[illegible], 8 7 acres
Average distance [illegible] 104 rods

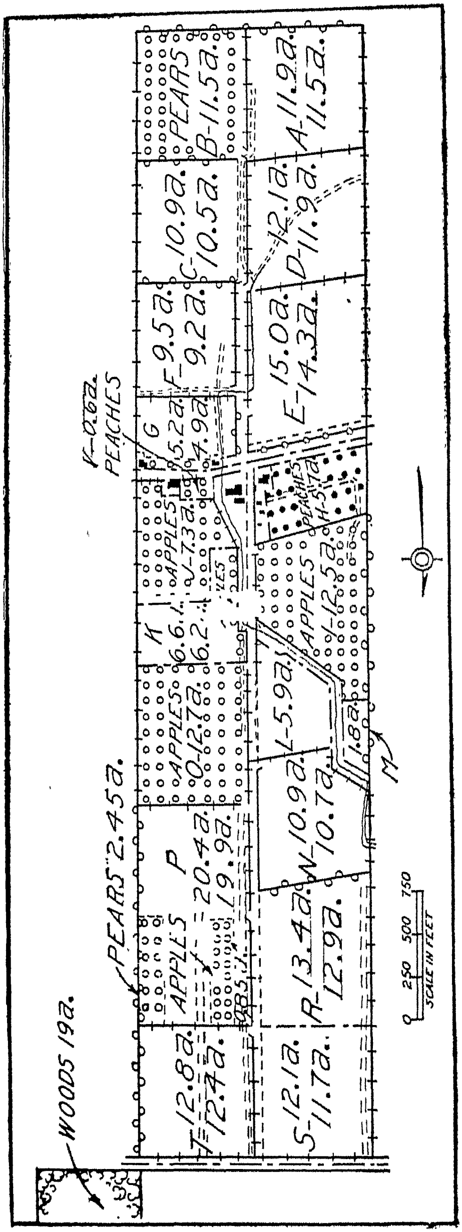


FIG. 108. A MUCH BETTER PLAN THAN THAT SHOWN IN FIGURE 105

Altho the farms are of nearly the same proportions, the farmstead in this case is nearer the center of the farm

Farm area, 228.2 acres
Average size of farmed fields, 9.7 acres
Average distance to farmed fields, 87 rods

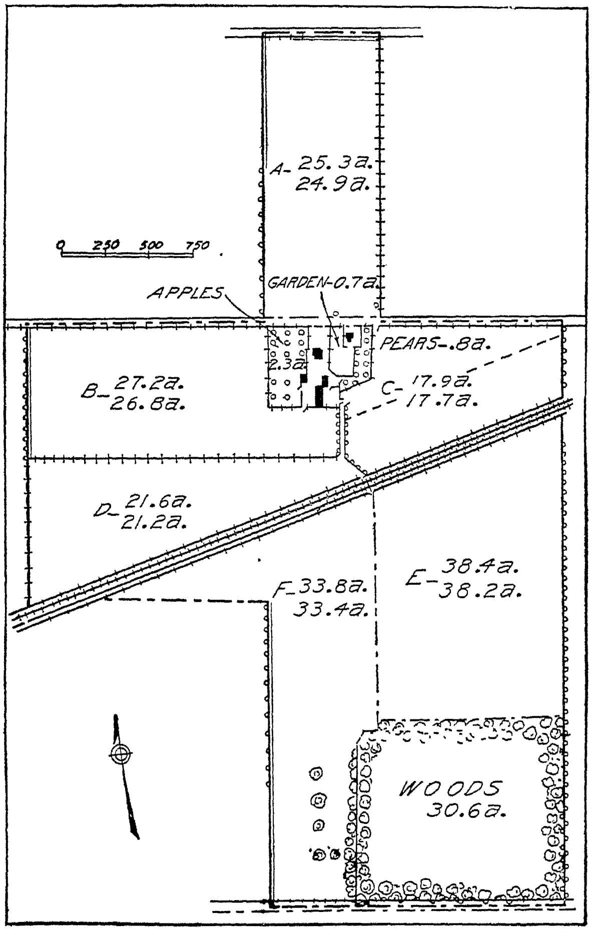
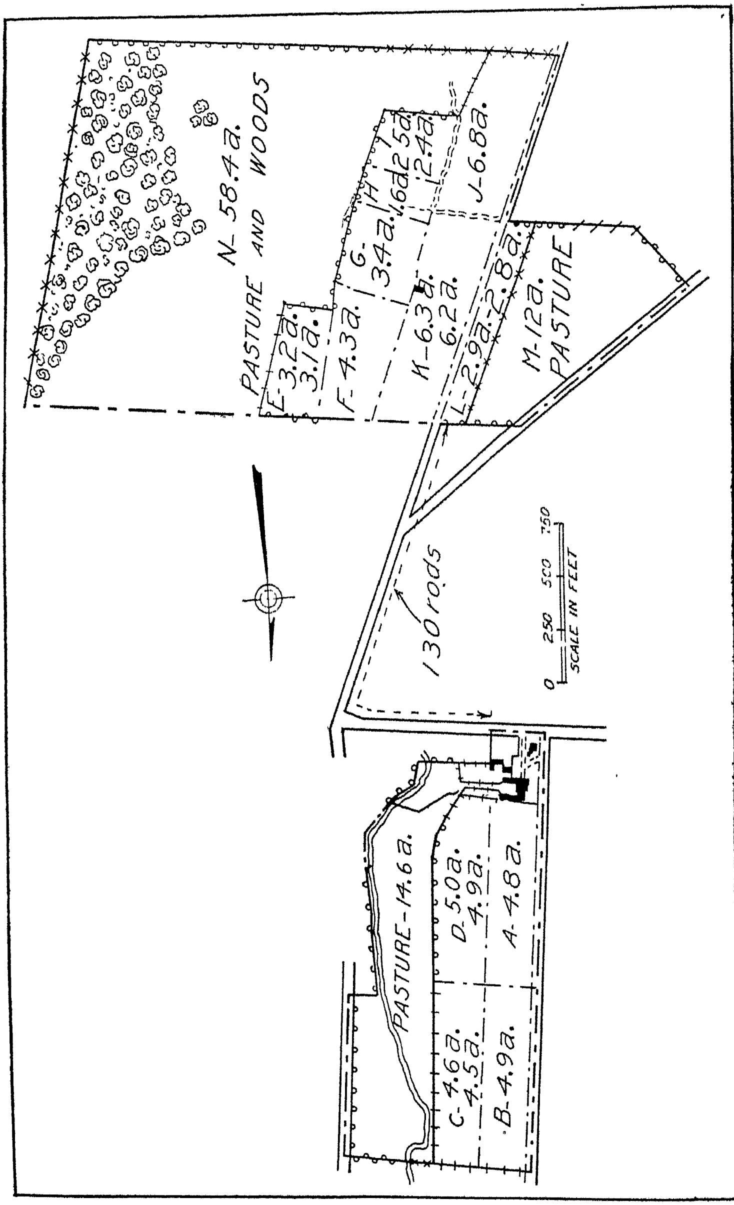


FIG. 109. A GOOD FARM LAYOUT IN WESTERN NEW YORK

All of the fields can be reached from the farmstead with a minimum of travel. The fields are large, but some of them are very irregular. Field A has rows 100 rods long and is almost ideal for efficient operation

Farm area, 204.4 acres
Average size of farmed fields, 27 acres
Average distance to farmed fields, 30 rods



N- 58.4a.
PASTURE AND WOODS
E-3.2a.
3.1a.
F-4.3a.
G-
3.4a.
H-
1.6a.
2.5a.
I-
2.4a.
J-6.8a.
K-6.3a.
6.2a.
L-2.9a.
2.8a.
M-12a.
PASTURE
130 rods
0 250 500 750
SCALE IN FEET
PASTURE-14.6a.
D-5.0a.
4.9a.
A-4.8a.
C-4.6a.
4.5a.
B-4.9a.

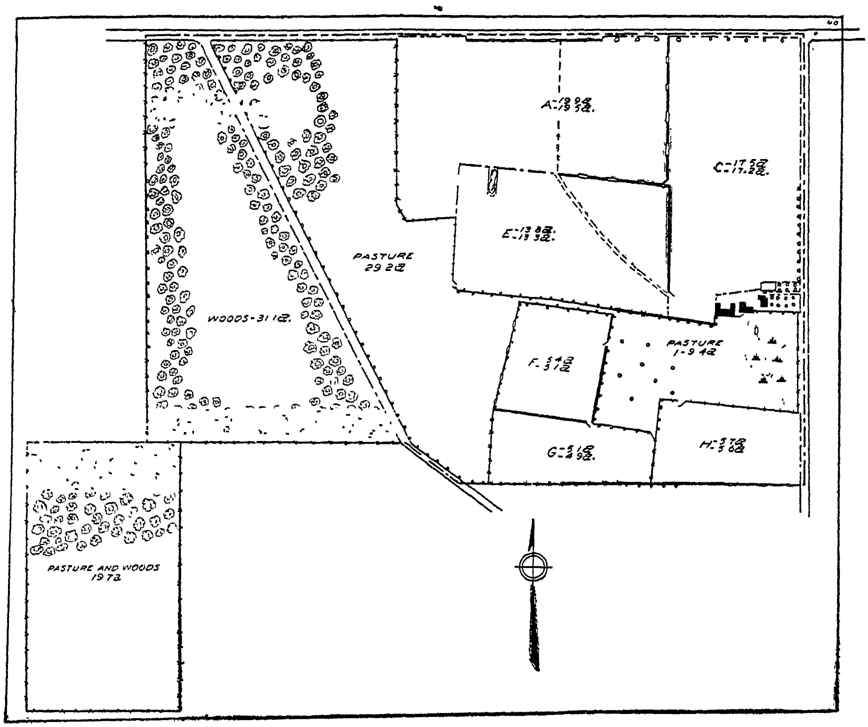


FIG. 111. A CENTRAL NEW YORK FARM OF APPROXIMATELY THE SAME AREA AS THAT SHOWN IN FIGURE 110, BUT WITH AN AVERAGE DISTANCE TO FIELDS ONLY ONE-FOURTH THAT OF THE OTHER FARM

Obviously this farmer has a decided advantage in producing crops

Farm area, 162 acres
Average size of farmed fields, 10.9 acres
Average distance to farmed fields, 33 rods

OBSTRUCTIONS IN FIELDS

The difficulties in farming the small, irregularly shaped fields found on many farms are in some cases further increased by obstructions of various kinds. Not only do these obstructions waste land, but, what is usually more important, they waste labor in farming around them.

Swampy spots

Wet, swampy spots in cultivated fields are frequently found on farms located on the heavier soils of the State. On the fifty-three farms included in these studies a total of more than 30 acres of land in cropped fields was occupied by such waste areas, or an average of nearly 0.6 acre for each farm. In addition to this, much crop land needs some drainage. The area given includes only land in cropped fields actually untillable because too wet.

Not only do these wet, swampy places waste land that is otherwise good, but they hinder the cultivation of the remainder of the fields in which they are located. Where such areas can be drained easily, it frequently pays to drain them because of the saving of land and labor.

The plan of a western New York farm is shown in figure 112. In 1917 the swampy patch in field R was drained by a line of tile running to the corner of the open ditch in field B. Sixty rods of tile was necessary. The total cost of the job including work and tile, as shown by cost accounts, was \$103, or approximately \$1.70 a rod. Six-tenths of an acre of crop land, worth \$60, was gained. The net cost of the improvement was, therefore, \$43. The work was done by farm labor at odd times. At the same time the brush row between fields P and R was cleared, permitting fields P, R, and S to be farmed as one field of 21 acres. This arrangement allowed the elimination of the driveway to field S. The saving in land and labor with the new arrangement will pay for the entire cost in a few years.

Open ditches and streams

On the farms studied, a total of 37.2 acres of land in cropped fields, or an average of about 0.7 acre for each farm, was occupied by open ditches or by streams (figs. 113 and 114). Open ditches are continually filling up with dirt and weeds, so that the annual upkeep is a considerable item. More important is the fact that they often divide the crop land into fields of irregular shape.

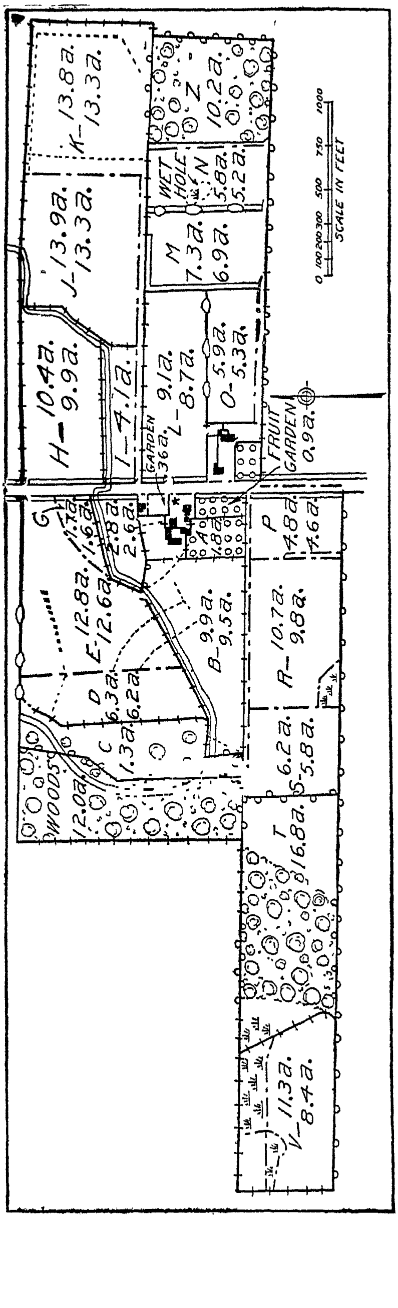


FIG. 112. A FARM IN WESTERN NEW YORK

In 1917 the swampy hole containing 0.6 acre in field R was drained by a line of tile running to the corner of the open ditch in field B. At the same time the brush row between fields P and R was cleared, allowing fields P, R, and S to be combined into one field of 21 acres

Farm area, 193.1 acres
Average size of farmed fields, 7.4 acres
Average distance to farmed fields, 73 rods

Frequently the possible saving of land and labor justifies the elimination of these obstructions to cultivation. An improvement of this kind is shown in figures 115 and 116. Plan 1 in figure 115 shows the layout of 50 acres which form part of a farm of 160 acres. The open ditch shown in this plan divided this area, as indicated, into irregular fields. With all

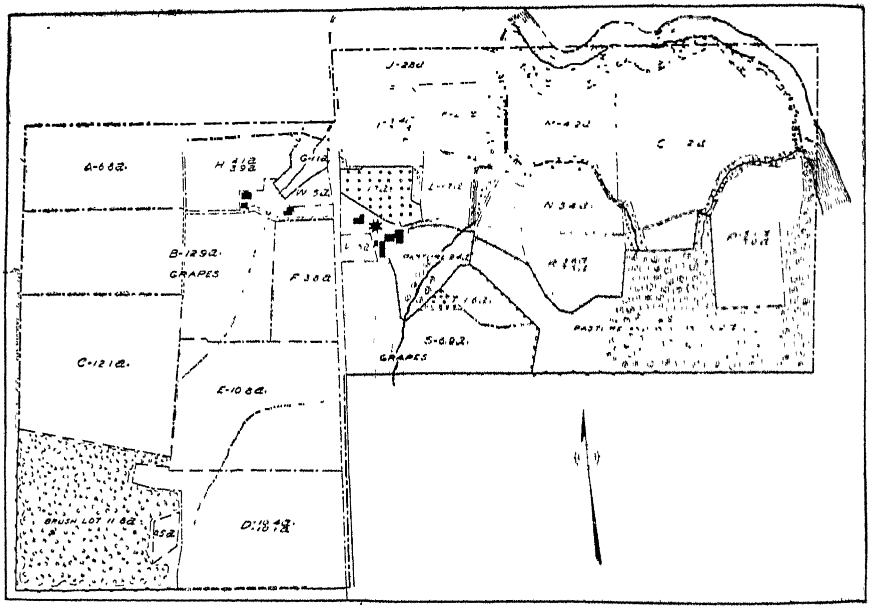


FIG. 113. A WESTERN NEW YORK FARM HAVING MANY FIELDS OF IRREGULAR SHAPE, MOST OF THESE BEING DUE TO OPEN DITCHES GROWN UP TO ALDERS. THE DITCHES COULD BE EASILY TILED

Farm area, 153.3 acres
Average size of farmed fields, 5.9 acres
Average distance to farmed fields, 53 rods

the fields in corn there would have been more than two hundred short rows. The ditch was grown up to brush and wasted a considerable area of land.

In the fall of 1916 this ditch was tiled up to the south end of field T. In the spring of 1917 the land along the ditch was cleared and plowed for cropping. The costs of making this improvement were as follows:

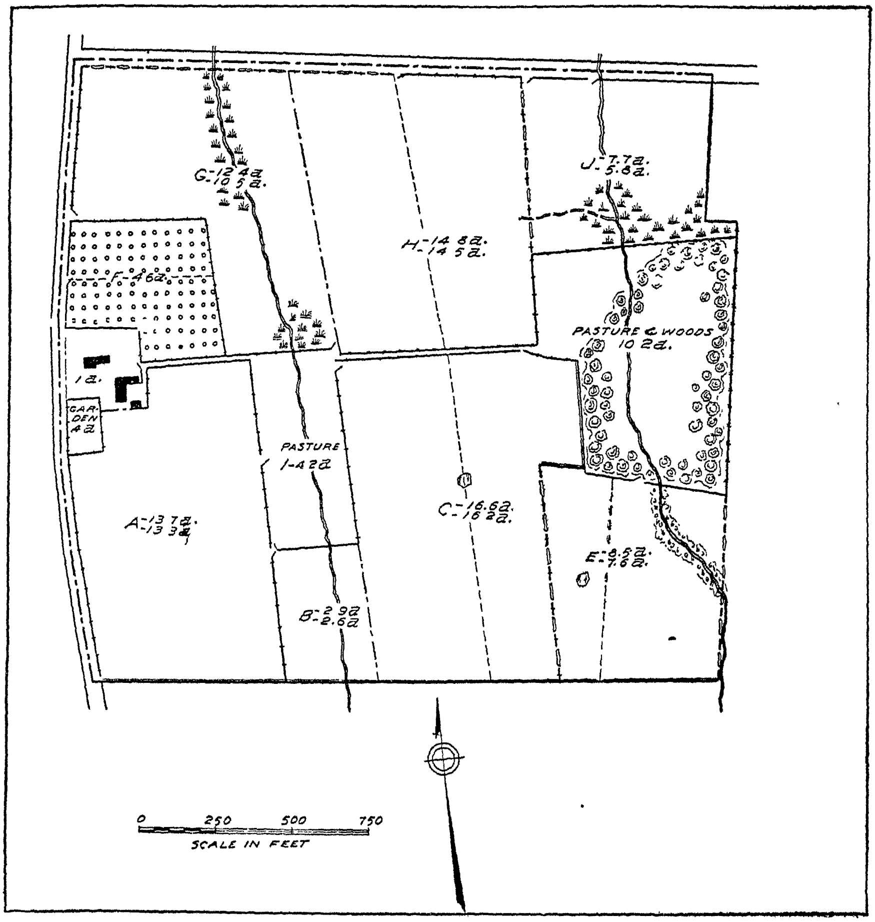


FIG. 114. A WESTERN NEW YORK FARM ON WHICH A CONSIDERABLE AREA OF LAND IS WASTED BY STREAMS

The small stream in field G wastes 1 7 acres of land and makes the remainder of the field difficult to farm. By deepening and straightening the stream bed, or by tiling it, this field could be greatly improved About the same area of land is wasted by another small stream in field J. Land is worth $100 an acre here

Farm area, 100 2 acres
Average size of farmed fields, 9.4 acres
Average distance to farmed fields, 54 rods

Cost of 123 rods of tile drain:

1000 two-inch tile, 14 inches long	$16.32
350 three-inch tile, 14 inches long	8.75
325 four-inch tile, 14 inches long	14.62
55 six-inch tile, 14 inches long	3.85
1 roll roofing to cover joints	2.50
331 hours man labor	44.12
98 hours horse labor	9.80
98 hours use of equipment	2.94
Total cost of 123 rods of tile drain	$102.90
Cost per rod	0.84

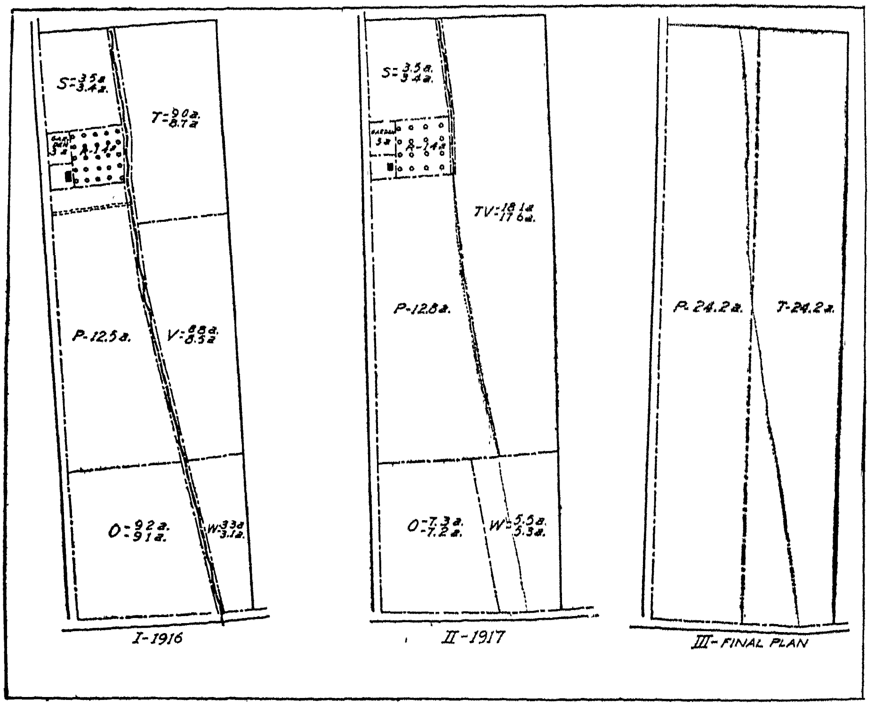


FIG. 115. PLANS OF A 50-ACRE TRACT SHOWING ARRANGEMENT BEFORE AND AFTER TILING AN OPEN DITCH

In the fall of 1916 and the spring of 1917, the open ditch was tiled as shown and the land formerly occupied by it was cleared for cropping. After completing the tiling, clearing the worthless orchard, and moving the tenant house, the owner will work the tract in two large, oblong fields, as shown in III

Cost of clearing land for cultivation:	
49 hours man labor	$ 7.39
74 hours horse labor	15.16
74 hours use of equipment	2.63
Total cost of clearing land for cultivation	$25.18
Total cost of laying tile and clearing land	$128.80
Cost per rod of laying tile and clearing land	1.04

FIG. 116. THE SAME FIELD (FIG. 115) IN 1918 AFTER THE TILING OF THE OPEN DITCH AND THE CLEARING OF THE LAND FOR CULTIVATION

One acre of land, worth $75, was gained, making the net cost of the improvement $53.08. The saving in labor made possible by enlarging and improving the shape of the fields will pay this in a short time. The work was all done by farm labor in the late fall and early spring, when other work was not pressing.

Plan III shows this owner's ultimate plan for this part of his farm. The house shown in Plan II is too far away from the main farmstead and will be moved to a more convenient location. The apple trees have never borne a commercial crop. They will be cut for firewood and the remainder of the ditch will be tiled, making possible the division of this tract into two rectangular fields of 24.2 acres each, 160 rods long. Since a tractor is used on this farm, the new arrangement will make possible an important saving in labor.

Stone piles

The abundant crop of stones found on a large part of the farm land of the State has given rise to many farm layout problems. In early days, when labor was cheap, stone fences furnished an excellent way of getting

FIG. 117. SMALL, SCATTERED STONE PILES WHICH WASTE BOTH LAND AND LABOR

FIG. 118. A LARGE STONE PILE IN THE CORNER OF A CROP FIELD

This stone pile occupies little land and does not interfere with cultivation. The stones are convenient for drawing if needed for improved highways

rid of surplus stones. In more recent times, changed conditions have made stone fences not only too expensive to build but also undesirable. On many farms the surplus stones have been thrown into small piles scattered at random over the different fields (fig. 117). Not only do such piles waste more land than do larger piles (fig. 118), but they waste labor in farming around them.

Trees

Some trees in pasture fields are desirable or shade; but trees in cultivated fields are inconvenient to farm around, and they damage the crop for a considerable area. On one of the farms included in this study a worthless apple orchard was cleared for cultivation in 1916. There were twenty-seven trees from sixty to seventy years old, averaging from 18 to 24 inches in diameter. They occupied an area of 0.6 acre. The cost of cutting the trees and clearing the land for cultivation was as follows:

50 pounds dynamite and wages of expert	$17.00
239 hours man labor	31.86
36 hours horse labor	3.59
36 hours use of equipment	1.04
Total cost	$53.49

Six cords of 4-foot firewood was cut, worth $6.50 a cord, or a total of $39. Six-tenths of an acre of crop land, worth $45, was gained. In this case the cost of clearing the orchard was more than paid by the value of the wood and of the land gained.

FENCES

The early settlers on New York farms made fences of rails, stumps, or stones, or of combinations of these materials. These fence rows were difficult to mow and keep cleared, and consequently were ideal for the propagation of brush and trees. As more surface stones were picked up from the land, they were often thrown into the fence rows. Changing conditions have made desirable the elimination of many fences in order to permit the enlargement of fields, but the wide, stony, brush-grown fence rows have proved a serious obstacle to this change. The increase in land values has made the land occupied by fences a factor worthy of con-

tion. Labor is no longer cheap, and fencing materials must be ased at increasing prices. As a result of these changes, the problem cing farms suitably and economically has become an important one. e various kinds of fences found on the fifty-three farms studied are given ole 11, together with data concerning the amount of each kind found:

BLE 11. Kinds of Fences and Amounts of Each on 53 New York Farms

Kind of fence	Total length of fence		Length of fence per farm (rods)	Per cent of total fencing
	Rods	Miles		
n wire	28,355.0	88.6	535.0	35.3
d wire	26,797 5	83.7	505.6	33.4
	6,492 4	20.3	122.5	8.1
rail	5,777.5	18.1	109.0	7.2
l	3,067.3	9.6	57.9	3.8
ht rail	2,903.1	9.1	54.8	3.6
	1,990.0	6.2	37.5	2.9
th wire	1,615 2	5.0	30.5	2.0
oad-owned (all woven wire)	772.3	2.4	14.6	1.0
e	711.8	2.2	13.4	0.9
pile	583.3	1.8	11.0	0.7
p	526.1	1.6	9.9	0.7
t	436.7	1.4	8.2	0.5
	279.0	0.9	5.3	0.3
Total	80,307.2	250 9	1,515.2	100.0

t is difficult to define a fence. In table 11, any well-defined barrier to ivation between crop fields, and all pasture fences in use, are considered be fences. This explains the inclusion of stone-pile and brush fences separate classes in the table. They waste land, but will not turn stock. the other hand, many wire fences will not turn stock. In general, more land a fence wastes, the less efficient it is in performing the most portant function of a fence.

Woven wire and barbed wire are the most important fencing materials ed on New York farms, as shown in table 11. Together they constitute re than two-thirds of the fences found on these farms. They are practi-lly the only kinds of fence being built under present conditions, and hence ey will become more important as they replace other types. On these rms a little more woven-wire than barbed-wire fence was found. Stone

fences were important in the southeastern and western parts of the State, but made up only eight per cent of the total fence. Virginia, or worm rail, fences are still found on many farms. These and other wooden fences have survived from earlier days when lumber was cheap. They are too expensive to build and maintain under present conditions, and are rapidly being replaced by wire fences. Board fences will continue to be used to some extent as barnyard fences to shelter stock from winds.

Relation of type of farming to fencing practice

The relative importance of different types of fencing varies widely in different parts of the State. This is to be expected, since the respective localities shown in table 12 represent distinct types of farming, with different fence requirements.

TABLE 12. IMPORTANT KINDS OF FENCING IN DIFFERENT REGIONS OF NEW YORK

Western New York 24 farms		Southern New York 11 farms		Southeastern New York 4 farms		Central New York 12 farms	
Kind of fence	Per cent of total fencing	Kind of fence	Per cent of total fencing	Kind of fence	Per cent of total fencing	Kind of fence	Per cent of total fencing
Woven wire.	55.1	Barbed wire.	64.8	Barbed wire	52 0	Barbed wire	37.2
Barbed wire.	11.1	Board. . .	8.9	Stone . . .	35.7	Woven wire	36.5
Worm rail . .	10.0	Woven wire	8.5	Straight rail	4 5	Worm rail. . .	5.3
Stone.	8.3	Worm rail. .	6 0	Board.	3 8	Board.	4.2
Straight rail.	5 5	Stone. . . .	3.1	Worm rail.	1 5	Straight rail	3.6
Hedge.	2 2	Smooth wire.	1.4	Smooth wire.	0.6	Stone.	3.4

Western New York

The twenty-four farms included in the western New York group are located in the counties of Erie, Genesee, Livingston, Monroe, Niagara, Ontario, Orleans, Seneca, and Yates. On these farms more than half of the fencing was of woven wire, while barbed wire formed but 11 per cent of the total. Worm rail, stone, straight rail, and hedge follow next, in order of use. These types are relics of earlier times, and all except the stone are rapidly disappearing.

The farms in this group are largely devoted to fruit and general farm crops. The farms averaged 128.6 acres, of which 97.1 acres were in crops. They had an average of five cattle units and 16 acres of permanent pasture per farm. Only two of the farms had more than six cows. On three farms a few sheep were kept. Land in this region is relatively high-priced, these farms averaging $120 an acre. Under such conditions, the experience of these farmers indicates that woven wire is the most desirable kind of fence. The small areas of permanent pasture are usually pastured by the family cow and the horses, with occasionally a few sheep. Barbed wire is too dangerous where horses form a considerable proportion of the stock pastured, and it will not restrain sheep. In answer to the question "What kind of fence do you consider best for your conditions?" all the farmers except one in this region expressed a preference for woven wire with one strand of barbed wire on the top. The single exception was the owner of a farm with no pasture, who preferred no fence at all.

Perhaps even more reliable than these answers as an indication of the most desirable fence for western New York conditions is the record of fence purchases. Cost accounts on these farms for the years 1914 to 1917, show that a total of 1070 rods of woven wire fencing have been bought and but 1314 rods of barbed wire. This amount of barbed wire is little more than enough to furnish a single strand of barbed wire to put above the woven wire.

Southern New York

The eleven southern New York farms are located in the counties of Cattaraugus, Chemung, Wyoming, and southern Cortland. Barbed wire constitutes about two-thirds of the fence on the farms studied in this region, with smaller amounts of board, woven wire, worm rail, stone, and smooth wire. As in other regions, the board and worm-rail fences are fast being supplanted by wire fencing.

These farms averaged 166 acres each, of which 101.6 acres were in crops and 49.6 acres in permanent pasture. They had an average of 22.1 cattle units to each farm, and all but two of the farms had more than six cows. Land in this region is relatively cheap, these farms averaging $67 an acre. Under these conditions barbed wire has been proved by experience to be the most desirable fence, considering all factors. The typical fence in this region is of three- or four-strand barbed wire. Where large areas of

cheap pasture land are to be inclosed, this in undoubtedly the cheapest fence that will satisfactorily turn stock. The principal stock pastured is cattle. As the number of horses pastured is comparatively small, the danger of injury to stock by barbed wire is not great enough to justify inclosing the large areas of pasture by a more expensive fence, such as woven wire. Again, it is difficult to stretch woven wire where the topography is as rolling as it is in most of this region.

All except two of the farmers in this group believed barbed wire to be the best fence for their conditions, considering all factors. These two expressed a preference for woven wire because of danger of injury to stock by barbed wire. The typical fence favored by most of these farmers was a four-strand barbed wire, stretched tight, with chestnut posts. The cost accounts on these farms show that a total of 1913 rods of barbed wire was purchased during the years 1914 to 1917, as against 140 rods of woven wire. This would indicate that nearly four rods of barbed wire fence are being built on these farms to one rod of woven wire.

Southeastern New York

There were only four farms studied in southeastern New York, all of these being located in Orange County. Barbed wire leads in the kinds of fence found on these farms, constituting more than half of the total fencing. Stone fence forms more than a third of the total, and the small remainder is made up of straight rail, board, worm rail, and smooth wire. Less wooden fence is found in this section of the State than in other sections. This is to be expected, since this region was settled first and practically all of the wooden fence materials have now disappeared.

The four farms in this region averaged 135.1 acres each, of which 72.3 acres were in crops and 52.6 acres were in permanent pasture. They had an average of 22.4 cattle units to each farm, being intensive dairy farms with one exception. Land in this region is relatively cheap. Under these conditions, barbed wire has been found to be the most satisfactory fence, utility and price considered. The typical fence in this region is three-strand barbed wire with more or less stone along the bottom. The same conditions that make barbed wire the most desirable fence in southern New York obtain in this region — large areas of cheap pasture land, uneven topography, and cattle the principal stock pastured. Four-strand barbed wire, stretched tight, with chestnut or oak posts, was considered by these

dairymen to be the best fence for their conditions. Cost accounts on these farms show that 1544 rods of barbed wire have been purchased during the years 1914 to 1917, as against 30 rods of woven wire.

Central New York

The twelve farms included in the central New York group are located in the counties of Cayuga, Onondaga, Oswego, and Tompkins. On the farms studied in this region, barbed wire and woven wire fences are of equal importance, each constituting a little more than a third of the total fence. Worm rail, board, straight rail, and stone are found in small amounts.

These farms averaged 275 acres each, of which 156.3 acres were in crops and 99 acres were in permanent pasture. They had an average of 31.3 cattle units to each farm, and all farms except one had more than six cows. Land is neither as cheap as in southern New York nor as high as in western New York, averaging $74 an acre on the farms studied. The average size of these farms was much larger than that of the farms in other regions, due to the inclusion of four unusually large farms. This region represents conditions intermediate between those of southern and those of western New York, and it is but natural that fencing practice should likewise be intermediate. On six of the twelve farms, woven wire was used the most for fencing. All except one of these were dairy farms, but they grew large areas of general crops as well. On the other six farms, barbed wire was used the most for fencing. These were all more intensive dairy farms. They had about the same area of pasture and the same number of cows, but land was cheaper, averaging $54 an acre as against $90 an acre for the six farms having a larger proportion of woven wire. The determining factor seemed to be the value of the land. In New York cheap land is usually fenced with a cheap fence, barbed wire, while good land justifies the best fence, woven wire. Little barbed wire fencing is found on New York farm land worth $100 or more an acre.

Distribution of fence on farms

The division of farm fences into four general classes with reference to their location on the farm, is shown in table 13. Practically no temporary interior fences were found on the farms studied, and so this classification is omitted.

TABLE 13. RELATION OF SIZE OF FARMS TO DISTRIBUTION OF FENCE

Size of farms (acres)	Number of farms	Road fence (per cent)	Boundary fence (per cent)	Interior fence (per cent)	Farmstead fence (per cent)
Less than 100	13	9	46	43	2
100–159 9	18	12	41	45	2
160–239.9	15	15	38	46	1
240 or more	7	16	35	48	1
Total	53	......	....	....	....
Average	... .	13	39	46	2

Not all of the roadside or the boundary lines or the field division lines of farms are fenced. The figures given in table 13 are concerned only with fenced farm divisions. In table 14 is shown the distribution of all farm division lines, both fenced and unfenced, and how the distribution is affected by the size of the farm.

TABLE 14. RELATION OF SIZE OF FARMS TO DISTRIBUTION OF FARM DIVISION LINES

Size of farms (acres)	Number of farms	Farm roadsides (per cent)	Farm boundary lines (per cent)	Interior field division lines (per cent)	Farm-stead division lines (per cent)
Less than 100	13	11	36	51	2
100–159.9	18	15	33	50	1
160–239.9	15	17	32	50	1
240 or more	7	19	33	47	1
Total	53	....	....	....	....
Average	... .	16	33	50	1

The relation of size of farms to the proportion of farm division lines fenced is shown in table 15. The larger farms were more completely fenced, 84 per cent of all farm divisions of the largest farms being fenced as compared with only 65 per cent for the smallest farms. Nearly as large

TABLE 15. RELATION OF SIZE OF FARMS TO PROPORTION OF FARM DIVISION LINES FENCED

Size of farms (acres)	Number of farms	Per cent fenced				
		Roadsides	Boundary lines	Interior field division lines	Farmstead division lines	Total farm division lines
Less than 100	13	52	82	55	78	65
100–159.9	18	53	84	61	88	68
160–239.9	15	64	91	70	88	76
240 or more	7	72	89	85	75	84
Total	53	....	....	......	......	....
Average	......	62	87	69	83	74

a proportion of the farm boundary lines of small farms were fenced as of the large farms, but a much smaller proportion of the roadsides and the interior field division lines.

Economy of fencing

The relation of size of farms to economy of fencing is shown in table 16. In comparing the rods of fence to the acre on these farms as shown by the "Fenced" columns in the table, it should be remembered that the larger farms are more completely fenced. The "Total" columns in table 16 show the economy that would obtain with larger farms if all

TABLE 16. RELATION OF SIZE OF FARMS TO ECONOMY OF FENCING

Size of farms (acres)	Number of farms	Rods per acre									
		Farm roadsides		Farm boundary lines		Interior field division lines		Farmstead division lines		Total farm division lines	
		Total	Fenced	Total	Fenced	Total	Fenced	Total	Fenced	Total	Fenced
Less than 100	13	1.9	1.0	6.1	5.0	8.6	4.8	0.3	0.3	17.0	11.0
100–159.9	18	2.0	1.1	4.5	3.8	6.8	4.2	0.2	0.2	13.6	9.2
160–239.9	15	2.1	1.4	3.8	3.4	6.0	4.2	0.1	0.1	12.0	9.1
240 or more	7	1.6	1.2	2.9	2.6	4.1	3.5	0.1	0.1	8.7	7.3
Total	53	.	...	....	.....	..	...	....	.....	....	.....
Average	..	1.9	1.2	3.9	3.4	5.8	4.0	0.2	0.1	11.8	8.7

farm division lines were fenced. If all farm division lines on these farms were fenced, 17 rods of fence to an acre would be required on the smallest farms, but only 8.7 rods to an acre on the largest farms.

Land occupied by fences

A considerable area of crop land is made untillable by fences. On the fifty-three farms included in these studies, the total area of general crop

FIG. 119. A STONE ROW THAT FUNCTIONS AS A FENCE ONLY IN WASTING LAND AND IN FORMING A BARRIER TO CULTIVATION

This stone row occupies a strip of land 20 feet wide. Land here is worth $100 an acre

land thus made untillable amounted to 101.8 acres. Part of this is necessary and unavoidable, but a considerable proportion is neither necessary nor desirable under present conditions (figs. 119 and 120). The proportion of the land occupied by fences depends on the size of the farm, the size of the crop fields, the kind of fence, and the crops grown. While the large farms, among those studied, were more completely fenced, a smaller proportion of their area was occupied by fences, as is shown in table 17.

The data given in table 18 relate to the land made untillable by fences around crop fields. Fences between pasture fields or orchards occupy

TABLE 17. RELATION OF SIZE OF FARMS TO CROP LAND OCCUPIED BY FENCES

Size of farms (acres)	Number of farms	Average size of farms (acres)	Crop land occupied by fences		
			Per farm (acres)	Per cent of farm area	Per cent of crop land other than fruit
Less than 100	13	76.2	1.08	1.4	2.5
100–174 9	20	127.4	1.45	1.1	1.8
175 or more	20	282.6	2.92	1.0	1.8
Total	53	....	....	....	....
Average	....	173.4	1.92	1.1	1.8

FIG. 120. A WOVEN WIRE FENCE BETWEEN TWO CORNFIELDS

Even under the most favorable conditions, fences make untillable a considerable strip of ground. This wire fence occupies a strip of land 6 feet wide

practically no land; but with a fence separating two general crop fields, the width of the strip of land made untillable, as shown by table 18, would be doubled, and the number of rods of fence required to waste one acre of land would be one-half of that given in the table.

TABLE 18. RELATION OF KIND OF FENCE AND CROP TO LAND OCCUPIED BY FENCES

Kind of fence	Width of land made untillable, in feet (one side of fence only)				Rods of fence necessary to occupy one acre	Value of land occupied by each rod of fence, at $100 an acre
	Hay	Small grain	Cultivated crop	Average		
Smooth wire	2.3	3.0	3.8	3.0	871	$0.115
Smooth wire and stone	6.1	7.2	7.7	7.0	377	0.265
Board fence	2.6	3.1	3 4	3.0	871	0.115
Board fence and stone	6.0	5.0	7 2	6 1	435	0.230
Woven wire	2.6	3.3	3.4	3.1	852	0 117
Woven wire and stone	5.3	6.6	7.0	6.3	419	0 239
Barbed wire	2 9	3.4	3.7	3.3	793	0.126
Barbed wire and stone	5.9	8 4	7 6	7.3	362	0.276
Straight rail	3 4	3.5	3.9	3 6	733	0.136
Straight rail and stone	5.5	7.4	9 0	7.3	362	0.276
Laid stone fence	4 4	4.8	5.5	4.9	539	0.186
Laid stone fence and stone	8 5	11.8	12.3	10 9	243	0 411
Stone pile	5.7	6 0	6.1	5 9	445	0 225
Stump	5.4	5.8	7.0	6.1	435	0 230
Worm rail	5.6	6.1	7.6	6.4	411	0 243
Worm rail and stone	8 4	8.8	11 7	9.6	274	0 365
Brush	9 4	11 7	7.0	9.4	282	0 355
Hedge	7.7	10.6	10.4	9.6	276	0.362

With any fence, the width of land made untillable is least when the field is in hay and greatest when the field is in a cultivated crop. This is to be expected, since it is possible to get closer to the fence with a mower than with other tools. When small grains are grown, the width of the strip of waste land is greater than when hay is grown but less than when a cultivated crop is grown. The differences are not important but they are perceptible.

The width of waste land along many fences is increased by the accumulation of stones that have been taken from the field and thrown along the fence. Even a few stones along a fence are enough to double the necessary waste. The stones that project farthest out into the field determine the width of waste along the entire side of a field. These results show that the presence of stone along a fence approximately doubles the width of the strip of land occupied.

Smooth wire, board, and woven wire fences occupied the least land on these farms (fig. 121). Smooth wire will not turn stock satisfactorily and board fence is obsolete. Woven wire stretched tight with a strand of barbed wire on top turns stock satisfactorily without danger of injury and occupies little land. Putting a strand of barbed wire above woven wire fence has become an almost universal practice on New York farms. Without any danger of injuring stock, it prevents stock from crowding down the fence and thereby ruining it.

Barbed wire and straight rail fences waste slightly more land than does woven wire. It is impossible to cultivate as close to barbed wire as to

FIG. 121. TWO SIDES OF A WOVEN WIRE FENCE

On the left the brush is cut and the fence occupies but two feet of land. On the right the brush and the fence occupy a strip of land 6 feet wide

woven wire, because of danger of injury to horses. Straight rail fence would be too expensive to build new, but it furnishes a satisfactory way of using old but sound fence rails. Barbed wire is the cheapest satisfactory fence for inclosing large areas of cheap cattle pasture.

Stone fences are wider than wire fences and necessarily occupy more land. Stone-pile fence does not really deserve the name of fence. It functions as a fence only in being a barrier to cultivation and in wasting land. In early times stone fences furnished a satisfactory way of getting rid of surplus stones; in the present day they are serious barriers to the enlargement of fields, because of the expense of removing them. Good use has been made of some stone fences in the improvement of roads. Many

stone fences, particularly in the southeastern part of the State, are so wide and so high that the saving thru larger fields would not justify their removal unless the stones could be used for some such purpose.

Stump and worm rail fences waste much land, harbor weeds and woodchucks, and do not turn stock satisfactorily. Unless land is very cheap it will usually pay to replace such fences with wire.

Brush and hedge fences (figs. 122 and 123) are the most wasteful of land of all fences found on the farms studied. Neither of these fences

FIG. 122. AN UNTRIMMED HEDGE OCCUPYING A STRIP OF LAND 3 RODS WIDE WHERE LAND IS WORTH $150 AN ACRE

Every rod of this fence occupies nearly $3 worth of land. The cost of clearing 60 rods of similar hedge on this farm was 80 cents a rod

has a place on any New York farm, but unfortunately both are expensive to eradicate. Hedge fences are expensive to trim, but more expensive to let go. They waste much land, harbor insect pests and woodchucks, and do not turn stock satisfactorily. On land worth $100 an acre, the land actually occupied on both sides of an average hedge fence would be worth 72 cents a rod. In addition to the land actually occupied, hedge fences injure the crop for a considerable distance on each side.

FIG. 123. A CLOSELY TRIMMED HEDGE

Even closely trimmed hedges occupy a wide strip of land. This hedge actually makes untillable a strip of land 10 feet wide and injures the crop for some distance beyond this

Proportion of farm area in fenced fields

The proportion of farm area in fenced fields on the fifty-three farms included in this study, in its relation to the size of the farms, is given in table 19. This table shows a smaller proportion of crop area and of total farm area in fenced fields on the smaller farms than on the larger ones. The group of small farms includes a larger proportion of fruit and crop farms

TABLE 19. RELATION OF SIZE OF FARMS TO PROPORTION OF FARM AREA IN FENCED FIELDS

Size of farms (acres)	Number of farms	Average size of farms (acres)	Per cent of area in fenced fields			
			Crop land	Pasture land	Woods not pastured	Total
Less than 100	13	76 2	26	100	42	39
100–174 9	20	127.4	34	100	38	48
175 or more	20	282.6	47	100	16	64
Total	53	....	......	....	....	.....
Average	......	173.4	40	100	23	57

on which little stock is kept. On such farms fenced fields are often unnecessary and undesirable. The proportion of crop and farm area in fenced fields in its relation to the number of acres to each cow, is as shown in table 20:

TABLE 20. RELATION OF NUMBER OF ACRES TO EACH COW TO PROPORTION OF CROP AND FARM AREA IN FENCED FIELDS

Number of acres to each cow	Number of farms	Average number of acres to each cow	Average size of farms (acres)	Average number of cows to the farm	Per cent of area in fenced fields	
					Crop land	Farm area
20 or more	20	40.4	113.1	2.8	26	31
10–19	12	14.7	277.6	18.9	40	63
Less than 10	16	7.1	165.9	23.5	42	63
Total	*48	....	....	....	......	......
Average	....	12.5	171.8	13.7	36	54

* In this tabulation five farms were omitted because some sheep were kept in addition to the cows.

Relative advantages and disadvantages of fenced and unfenced crop fields

The question of fencing crop fields is one of considerable importance to farmers. There are many advantages and likewise many disadvantages in this practice. If fields are fenced, the stock can be pastured earlier in the spring and later in the fall than is otherwise possible, as well as in midsummer when permanent pastures are poor. Pasture is of the most value at these times, because it takes the place of barn feed. Cornfields can be pastured after the corn has been put into the silo; the scattered ears and stalks furnish a considerable amount of valuable feed. If seeding is done with wheat, the oat stubble may be pastured. Even in a stubble field the grass in the fence rows furnishes some feed, while the pasturing saves mowing by hand. Old meadows can be pastured in the fall and spring before they are plowed for corn. Aftermath in meadows is frequently pastured. It furnishes feed when permanent pastures are usually poor.

The disadvantages of fencing crop fields are also numerous. Fences prevent the adjustment of field lines to changed conditions. In going to

a fenced field, it is necessary to go around to the gate. When fields are fenced there is a tendency to turn stock on them at times when the crops and the land will be injured. Fence lines occupy a considerable area of land (figs. 124 and 125). In addition to the land that is left untilled, there is a waste in the crops that are injured along a fence by turning. The actual loss by fences is probably double the figures given in table 18 (page 469). The cost of maintaining fences is an important item and it is rapidly be-

Fig. 124. UNNECESSARY WASTE OF LAND BY FENCING
Every rod of this fence wastes land worth $1, besides furnishing an ideal protection for weeds, brush, and woodchucks. Field fences are unnecessary in this region since little stock is kept

coming more important. The actual cost of maintenance varies with the type of fence. It was probably between 5 and 10 cents a rod a year on most farms in 1919, when this study was made. In unfenced fields the aftermath and stubble not pastured are not entirely wasted if left on the land, as they serve as green manure and help to keep up the supply of humus.

The value of the feed from meadows depends on the cost of the feed which it replaces. If it replaces pasture, its value is approximately equal to the cost of pasture, usually about $1 to $2 a month for each cow. If

it replaces barn feed its value is approximately the cost of barn feed, which is very much higher than the cost of pasture.

Cost accounts were kept in 1916 and 1917 on forty of the farms included in these studies. On twenty of these the meadows were pastured to a greater or less extent. On eighteen farms of twenty-six which had ten or more units of stock other than horses to pasture, the permanent pasture was supplemented by pasturing meadows; of the other eight, one could

Fig. 125. UNFENCED FIELD LINES WHICH OCCUPY NO LAND AND DO NOT INTERFERE WITH CULTIVATION

On this farm little stock is kept and fenced crop fields are both unnecessary and undesirable

not pasture meadows because the soil was too sandy to hold grass well, and three had large areas of very cheap permanent pasture but little crop land. The farmers who pastured their meadows secured an average amount of pasture equivalent to the pasture of twenty-one cows for one month. This was equivalent to about one-fifth of the total pasture on these farms. The extra fence necessary for the fenced crop fields on these farms, in addition to permanent pasture, boundary, and lane fence, averaged 285 rods for each farm. At 6 cents a rod the cost of maintaining this extra fence would be $17.10 a year.

Gates

Gates should be placed where they will give the most convenient access to fields; usually this means as close to the corner of the field nearest the buildings as the nature of the ground will permit. Where a gate is inconveniently located, time or crops or both are wasted. On one of the farms studied, the gate to a 10-acre crop field fronting on the road was in the corner of the fence farthest from the buildings. This location made the distance from the barn to the field 27 rods longer, and every round trip to the field 54 rods longer, than if the gate had been in the nearest corner. With an average of six man trips and fourteen horse trips an acre in a year, about ten man miles and twenty-four horse miles of unnecessary travel each year is required to farm this field with the present arrangement.

The location of the gate is far more important than its construction. Farmstead gates which are opened and closed many times daily should be hinged so as to swing easily. Gates that swing both ways are preferable for such conditions. The weakest point in such gates, however, is the hinge, and therefore field gates are seldom hinged. The typical farm gate is the ordinary slide gate made of boards. This is easily built, cheap, and substantial.

Cost of fence maintenance

The combination of the data obtained in these studies with the cost-accounting records kept by the farmers made it possible to compute the actual cost of upkeep of the fences on these farms. The records for 1914, 1915, 1916, and 1917 were used, and all the farms were included each year for which sufficient data were available. A total of 105 records were obtained, representing forty-one farms. The data are given in tables 21 and 22.

The cost of work done in repairing and improving farm fences was obtained from the cost accounts. The actual hours of labor were taken from the work reports kept by farmers, and the cost per hour of man and horse labor is the actual farm cost for that year. Both labor and other costs of building new fence are included as upkeep costs, since with a number of farms it is a safe assumption that the new fence built in any year will approximately represent the normal necessary replacement. The labor data for mowing fence rows were obtained partly from the cost accounts and partly by estimates of the farmers. The cost per hour was taken from the cost accounts in each case. The amounts and cost of fencing, gates, posts, and other materials purchased, were taken from the

cost accounts in each case. The amount of crop land occupied by fences was obtained from the data given in these studies. The value of the land occupied by fences was determined for each farm from the area of land actually occupied and the value of this land as given in the accounts. Rental at 5 per cent on the value of land occupied was included as part of the cost of maintaining fences. The number of posts cut from farm wood-lots, and their value before cutting, were obtained from estimates by the farmers. The labor of getting out and splitting posts is included in the other labor on fences.

In computing the amount of fence maintained to each farm, it has been assumed that each farmer maintains half of the boundary fence of his farm. While not always true in individual cases, this should closely approximate the truth for a group of farms. All fences maintained by railroads, highway fences maintained by the State, and stone-pile and brush fences, were deducted in determining the amount of fence maintained to each farm. The present farm value of each kind of fence was determined from estimates by the farmers. Interest at 5 per cent on the present value of fences was included as one of the costs of maintaining them.

TABLE 21. KINDS, AMOUNTS, AND FARM VALUES OF FENCING MAINTAINED FOR WHICH THE COST OF MAINTENANCE WAS DETERMINED

Kind of fence	Total of 105 farm records		Per farm record		Average value per rod of fence
	Rods	Value	Rods	Value	
Woven wire	40,790	$18,422.21	388 5	$175.45	$0.45
Barbed wire	45,896	11,288 81	437.1	107.51	0.25
Stone	8,773	1,553 75	83.6	14 80	0.18
Worm rail	8,719	1,646.19	83 0	15.68	0.19
Board	6,108	1,353.45	58.2	12.89	0.22
Straight rail	4,372	1,011.18	41 6	9 63	0.23
Other kinds of fencing	6,318	1,063.45	60 2	10 13	0.17
Total	120,976	$36,339 04	1,152 2	$346.09	....

As shown in table 21, the average amount of fencing maintained to each farm was 1152 rods, or 3.6 miles, valued at 30 cents a rod. The average farm value of the fences in their present condition was $346.09 a farm, or about $2 an acre.

TABLE 22. COST OF MAINTAINING FARM FENCES ON FORTY-ONE NEW YORK FARMS FOR THE YEARS 1914 TO 1917, INCLUSIVE

(105 farm records, including 120,976 rods of fence)

Item	Total of 105 farm records		Per farm record		Cost per rod of fence maintained
	Amount	Cost	Amount	Cost	
Labor:					
Fence repairs:					
Man labor	7,414 hrs.	$1,305.33	70 6 hrs.	$12.43	....
Horse labor	2,536 hrs.	396.36	24.2 hrs.	3.77	....
Equipment use	2,536 hrs.	115.65	....	1.10	....
Total	....	$1,817.34	....	$17.31	$0.015
New fence:					
Man labor	2,188 hrs.	$439.55	20.8 hrs.	$4.19	....
Horse labor	743 hrs.	132.58	7.1 hrs.	1.26	....
Equipment use	743 hrs.	36.28	....	0.34	....
Total	....	$608.41	....	$5.79	$0.005
Mowing fence rows:					
Man labor	2,405 hrs.	$444.91	22.9 hrs.	$4.24	....
Horse labor	190 hrs.	28.20	1.8 hrs.	0.27	....
Equipment use	190 hrs.	9.60	....	0.09	......
Total	....	$482.71	....	$4.60	$0.004
Total labor cost	....	$2,908.46	....	$27.70	$0.024
Materials purchased:					
Fence posts	1,891	$246.17	18.0	$2.34	$0.002
Woven wire	1,695 rods	540.22	16.1 rods	5.14	0.004
Barbed wire	6,612 lbs.	253.33	63.0 lbs.	2.41	0.002
Other wire	386 lbs.	14.38	3.7 lbs.	0.14	0.0001
Staples	614 lbs.	29.75	5.8 lbs.	0.28	0.0002
Lumber for gates	....	47.60	....	0.45	0.0004
Total cost of materials	....	$1,131.45	....	$10.77	$0.009
Other costs:					
Rental at 5 per cent on value of land occupied by fences	....	$ 681.01	....	$ 6.49	$0.006
Value, before cutting, of posts cut from farm woodlots	6,455 posts	385.98	61.5 posts	3.68	0.003
Interest at 5 per cent on present farm value of fence maintained	....	1,816.87	....	17.30	0.015
Total of other costs	....	$2,883.86	....	$27.47	$0.024
Entire total cost	....	$6,923.77	....	$65.91	$0 057

The average cost of maintaining fences on these farms for the four years was 5.7 cents a rod. With 1919 prices this cost would be about doubled. The average costs by years for these farms are as follows:

23 farms, 1914	5.8 cents a rod
33 farms, 1915	5.7 cents a rod
26 farms, 1916	5.5 cents a rod
23 farms, 1917	5.9 cents a rod
105 farm records, four years	5.7 cents a rod

The variation on individual farms ranged from 2 to 12 cents a rod. Farm costs for any one year are greatly affected by the amount of fencing done in that year, but with a group of farms this factor is stabilized.

The cost by the rod of maintaining fence depends on the kind of fence. On fifteen farms having 75 per cent of barbed wire fence and only 7 per cent of woven wire, the average cost of maintaining fence was 4.9 cents a rod. On seventeen farms having 70 per cent of woven wire fence and only 4 per cent of barbed wire, the average cost was 6.8 cents a rod. On twenty-one farms having 26 per cent of woven wire fence and 28 per cent of barbed wire, the average cost was 5.5 cents.

Of the fences having posts, one post was used for every 12.3 rods of fence each year. Since posts are usually set about a rod apart, it appears that the posts last about twelve years.

FARM LANES AND DRIVEWAYS

In this discussion the word *lane* designates a fenced private passageway which is primarily used to make pastures accessible to buildings. Altho used for other purposes also, lanes are arranged chiefly to save time in getting stock to and from pasture. They are therefore necessarily fenced. The word *driveway* is employed to designate the land primarily devoted to use as a passageway to crop fields. Driveways therefore need not be fenced. They may vary in location from year to year. Driveways are necessary on practically every farm, while lanes are not.

Utility of lanes

Whether or not lanes are needed, their width, and the area of land to be devoted to them, depend chiefly on the size of the farm, the shape of the farm, the area of crop land, the value of the farm land, and the amount of stock kept.

On the farms included in this study, 51.5 acres of land were devoted to farm lanes and driveways, or slightly less than an acre to each farm. Of this area 24.8 acres were in lanes which were pastured by stock, 13.1 acres were in fenced driveways not pastured, and 13.6 acres were in unfenced driveways. The average width of lanes pastured was 39 feet, of fenced driveways 25 feet, and of unfenced driveways 11 feet. The fenced driveways were formerly used as lanes for stock. Since they are no longer necessary for this purpose, they waste a considerable area of land. Assuming the width of the unfenced driveways given above (11 feet) as necessary, the fenced driveways waste about 8 acres of land. Most of this could be reclaimed for crops at a reasonable cost.

The larger farms included in this study had a smaller proportion of their area in lanes and driveways than the smaller farms. The farms of less than 100 acres had 0.9 per cent of the farm area in lanes and driveways, while on farms of more than 175 acres 0.4 per cent of the farm area was used in this way. The corresponding proportions of the crop area were 1.2 per cent and 0.7 per cent, respectively.

The shape of the farm is usually of more importance than its size in its effect on the proportion of the farm area necessary for lanes and driveways. Long, narrow farms, in addition to their other disadvantages, require much larger proportions of their areas for this use. On one farm a part only 440 feet wide had a necessary driveway 16 feet wide thruout most of its length. As far back as the driveway extended it occupied about 4 per cent of the crop land. This is in a region where land is worth about $150 an acre. The plan of this farm is shown in figure 99 (page 439). The long, narrow farm shown in figure 96 (page 436) has 1.6 per cent of its area in lanes and driveways. Striking contrasts in this respect are presented in figures 105 (page 445) and 109 (page 449). The elongated farm has 1 per cent of its area in lanes and driveways, while the compact farm of the same size has only one-seventh as much land devoted to this purpose.

The necessity for farm driveways depends somewhat also on the arrangement of public roads. Farms which are so divided by public roads that the fields are readily accessible, often need but few private driveways. However, public roads do not take the place of lanes for stock.

The question as to whether or not a lane would be advantageous on a given farm depends on its cost and on the saving in labor that it would effect. If much stock is kept and the pasture is not adjacent to the buildings, a lane would usually be justifiable. Part of the layout of a farm of 368 acres is shown in figure 126. On this farm a lane connects the barns with the night pasture, but the cows are driven up the road to the day pasture. The distance from the barnyard gate to the gate of the day pasture is 148 rods. Two round trips must be made daily with the fifty cows kept on this farm, taking the cows to pasture in the morning and going after them at night. This makes the distance traveled daily nearly two miles and the time consumed with a herd of this size an hour a day. The normal pasture season on this farm is about 150 days, and this means 150 hours spent in driving cows. This work comes during the crop-growing season, when time is most valuable. At 30 cents an hour the cost of driving cows would be $45 a year.

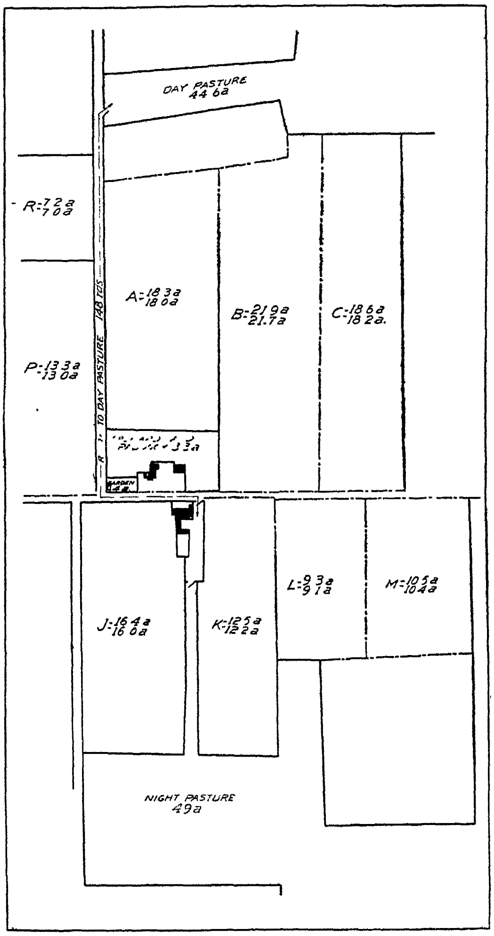


Fig. 126. PLAN OF A CENTRAL NEW YORK DAIRY FARM, SHOWING THE PRESENT ROUTE TO THE DAY PASTURE

Since there is no [illegible] be driven up [illegible]

A way in which this farm might be rearranged with a lane 4 rods wide running between fields A and B, con-

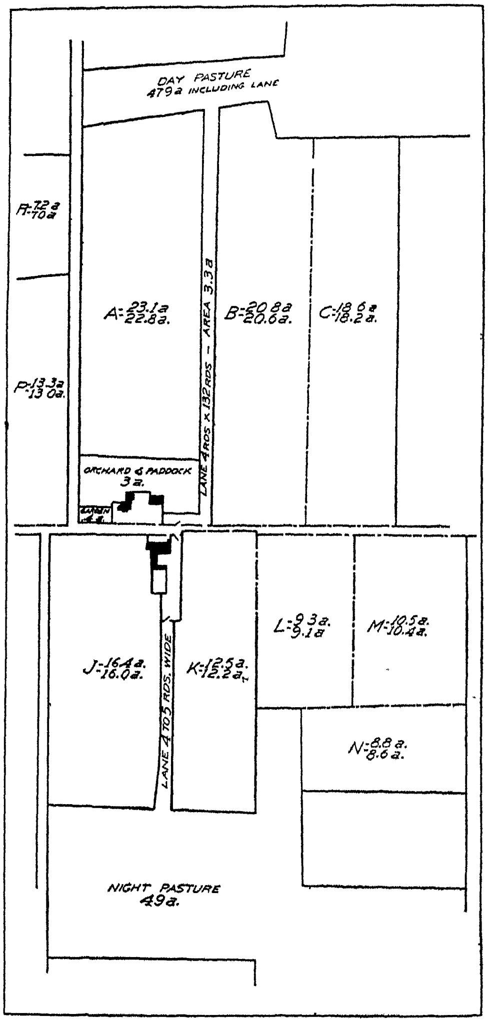


Fig. 127. PLAN OF THE FARM SHOWN IN FIGURE 126, ILLUSTRATING HOW A LANE COULD BE RUN FROM THE BARNYARD TO THE PASTURE, BETWEEN FIELDS A AND B

Such a lane would save much time, besides greatly lessening the danger of injury to the cattle by automobiles

necting the barnyard with the day pasture, is shown in figure 127. Some grain is fed to the cows all summer on this farm, and with such a lane very few trips would be required to get the cows.

A lane of this width would occupy 3.3 acres of crop land worth $60 an acre. Interest at 6 per cent on 3.3 acres of $60 land would amount to $11.88 a year. This land would not be wasted but would furnish considerable pasture. The length of good fence necessary for fencing this lane would be 264 rods. The dilapidated stone wall more than half a rod wide which separates fields A and B would not make a satisfactory lane fence, and therefore two new fences would be necessary. Since this lane would be used only by cattle, a four-strand barbed wire fence would be satisfactory. The annual cost of maintaining such a fence in 1918 would have been about $18. Using the figures given, the cost of land and fence for this lane would be about $30 a year. In this case a lane would effect a saving above

all costs of about $15 a year, besides furnishing some feed. It would also lessen danger of injury to cows by passing automobiles. If only one extra fence needed to be maintained, or if the pasture were used both night and day, the saving would be greater.

Width of lanes

Generally speaking, the width of a lane should be proportional to the number of cows using it. On the farms here under consideration, the average width of the lanes for herds of ten cows or less was 1.5 rods, for herds of from ten to twenty cows 2 rods, for herds of from twenty to thirty cows 3 rods, and for herds of more than thirty cows 4 rods. Wide lanes have many advantages. There is less danger of injury to cows thru crowding, and because of less crowding the cost of maintaining fences is less. Narrow lanes afford practically no feed at any time. In wet weather they are converted into mud holes, with the result that the cows come out with muddy legs and udders. Wide lanes preclude these disadvantages and furnish a considerable quantity of feed. They are substantially elongations of the pasture.

The proper width for a lane depends also on the character of the land, as well as on the number of cows using it. With wet land the lanes need to be wider in order to obviate mud holes. Under ordinary conditions the average widths given in the preceding paragraph should be satisfactory. The lane to the night pasture shown in figure 126 has good proportions for average soil conditions. It is used by fifty cows and varies from 4 to 5 rods in width.

In spite of the advantages of wide lanes it is not always advisable to have them. On long, narrow farms, a lane wide enough to furnish feed may take up too large a proportion of the tillable land. Under such a condition it may be better to waste land in a narrow lane than to make it wide enough to furnish pasture.

The location of most lanes is already fixed. New lanes should be so located that they run parallel to farm and field lines, in order not to make irregular fields. A poorly planned lane is shown in figure 128. Its direction was determined by the location of the buildings and the wet, untillable pasture at the back of the farm. Running the lane straight from the barns to this field, diagonal to the farm boundaries, made necessary many short rows on both sides. A peach orchard was planted with rows parallel to the lane, which made changing the lane difficult.

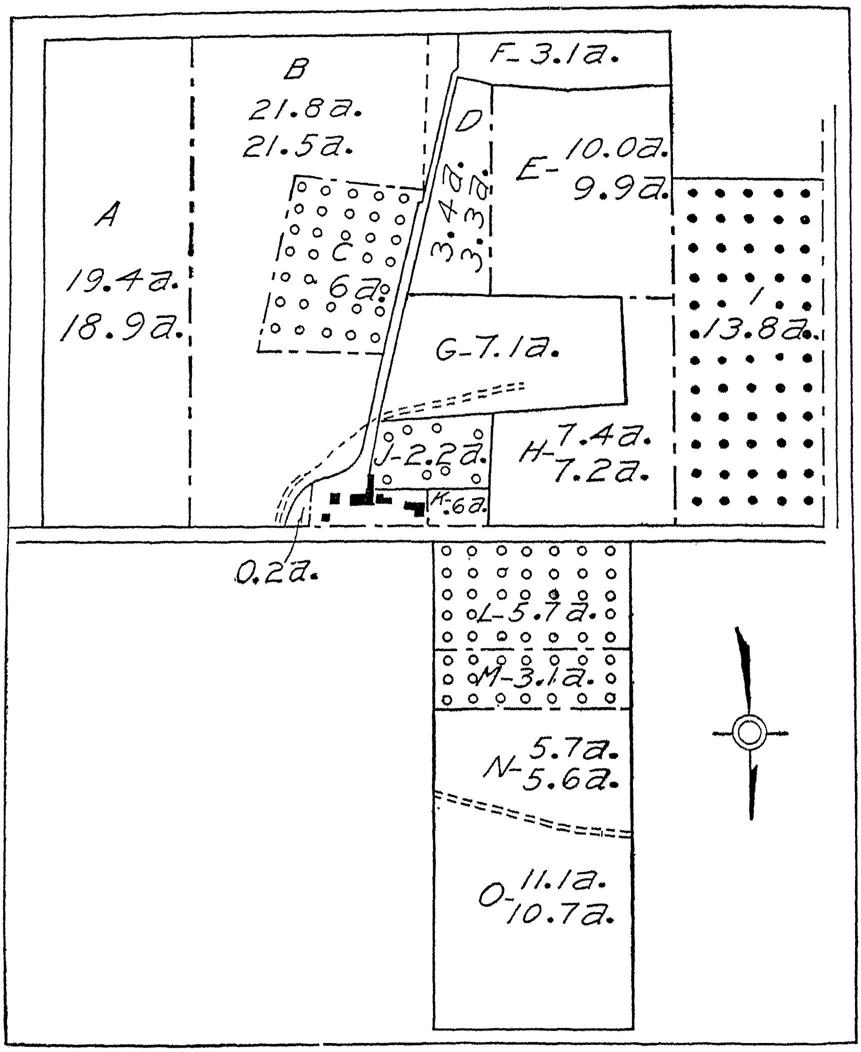


FIG. 128. FARM PLAN SHOWING A POORLY LAID OUT LANE

The lane was run from the buildings to the pasture at the back end of the farm, diagonal to the farm boundaries A peach orchard was later planted, with its rows parallel to the lane, making it difficult to change the lane. The diagonal course of this lane necessitated short rows and was the cause of much wasted labor

This lack of foresight has already cost a considerable amount in farming unnecessary short rows.

On some farms with little stock, lanes are unnecessarily wide and thus waste valuable crop land. The plan of a western New York farm is

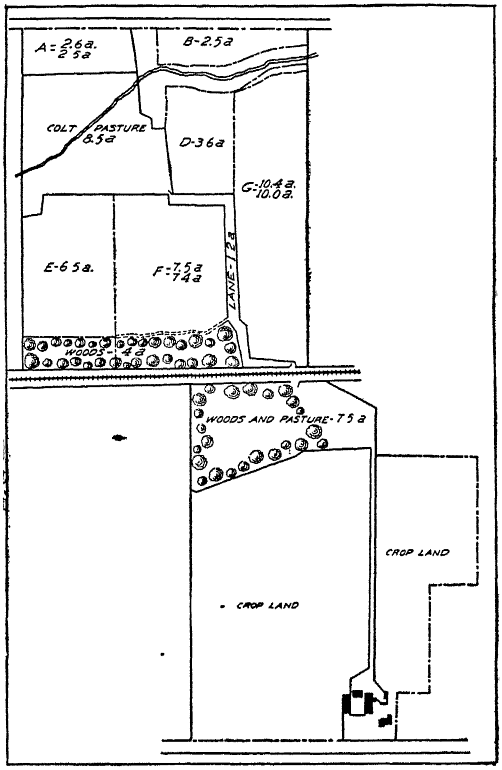


FIG. 129. PLAN OF A WESTERN NEW YORK FRUIT FARM SHOWING AN UNNECESSARY WIDE LANE WHICH OCCUPIES 1.2 ACRES OF TILLABLE LAND BETWEEN FIELDS F AND G

shown in figure 129. The lane between fields F and G is between 3 and 4 rods wide and occupies 1.2 acres of crop land worth $125 an acre. This lane leads to a pasture in a creek bottom, used for pasturing colts and heifers. It is too distant from the barns to be used for pasturing other stock. Two cows are kept for home use. A lane leads from the barns

to the pasture used by the cows and the horses. A way in which the same farm could be rearranged with an unfenced driveway replacing the former wide lane is shown in figure 130. The wide lane is not needed for pasture. For the type of farming followed, there is ample pasture

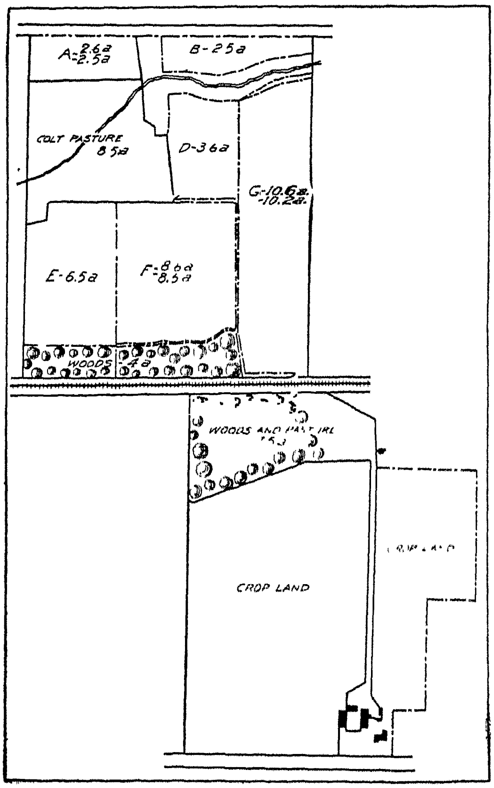


Fig. 130. Plan illustrating how the unnecessary lane shown in figure 129 could be eliminated, saving an acre of good land and the upkeep of 150 rods of fence

land which can be used for nothing else. The elimination of this lane would add about an acre of good land to the crop area and save the upkeep of 150 rods of fence. The saving would amount to about \$15 or \$20 a year.

Even if the advantages of a lane in this case were sufficient to pay the cost of fence upkeep, the lane is too wide for the amount of stock

kept. A lane of half this width would give ample room and save one-half of the land in the present lane. On a few farms having no permanent pasture, the lane is made wide enough to pasture the family cow until she can be turned out in the meadows, after haying.

CROP LAND

Crop land is the highest grade of farm land. The area adapted to crop production is relatively more limited than the area adapted to pasture and forestry. Crop land produces a greater net value of product to the acre than do other farm lands, and is therefore more valuable. For these reasons, all the land that can be economically worked under conditions existing at a given time is usually cropped at that time. Changing agricultural conditions affect both the amount and the quality of crop land. The change from hand labor to machine methods of production has reduced considerable areas of land in New York from crop land to pasture, since land that was not adapted to the use of machinery could no longer be economically cultivated. The opening-up of the rich lands of the Middle West had a similar effect in reducing crop land to pasture.

There is a large amount of farm land in New York State which is adapted for use only as pasture. If, therefore, land that can be economically cropped is used as pasture land, it loses its advantage and competes directly with cheap land which is good only for pasture. For this reason, usually little stock is kept unless part of the land is suited only for pasture, and practically all of the land adapted to economic crop production is used for crops.

To be suitable for crop growing, land must be not only adapted to cultivation by machinery but also reasonably fertile. Not all the land suitable for crop growing can be cultivated economically, however. Some of it may be so far from the buildings, or in such small, irregular fields, that farming it does not pay. A large part of the tillable land now in permanent pasture is too far away to be worked to advantage by its present owners. Such land is frequently convenient to the farmstead of an adjoining farmer. Readjustments in ownership which would permit each farmer to work the land most convenient to his farmstead would increase the area of crop land as well as increase the efficiency of labor.

The utilization of land in cropped fields on the farms studied is shown in table 23:

TABLE 23. LAND IN CROPPED FIELDS ON 53 NEW YORK FARMS

	Total number of acres	Number of acres per farm	Per cent of total farm area	Per cent of total area of cropped fields
Amount of land in cropped fields	6,076.86	114.66	66.12	100 00
Land in cropped fields not producing a crop:				
Fence rows	102.28	1.93	1.11	1.68
Swampy land	30.34	0.57	0.33	0.50
Streams	24.46	0.46	0.27	0.40
Open ditches	12.66	0.24	0.14	0.21
Driveways in crop fields	11.43	0.22	0.12	0.19
Rough or steep land	11.27	0.21	0.12	0.19
Land shaded by woodlots	6.68	0.13	0.07	0.11
Trees in fields	5.25	0.10	0.06	0 09
Stone outcrops	2.17	0.04	0.02	0.04
Barns in fields	2.15	0.04	0.02	0.04
Stone piles	1.42	0.03	0.02	0.02
Total crop land not producing a crop	210.11	3.96	2 29	3.46
Land in cropped fields producing a crop:				
Crops other than fruit:				
Not rotated:				
Permanent meadow	106.07	2.00	1.15	1.75
Gardens, etc	28 70	0.54	0.31	0.47
Total not rotated	134.77	2.54	1.47	2.22
Rotated:				
General crops	4,417.06	83.34	48.06	72.69
Truck crops	88.38	1.67	0.96	1.45
Crop land sometimes pastured	645.85	12.19	7.03	10.63
Total rotated	5,151.29	97.19	56.05	84.77
Total crops other than fruit	5,286.06	99.74	57.51	86.99
Fruit:				
Home and tenant orchards	44.76	0.84	0.49	0.74
Commercial fruit:				
Bearing	351 55	6.63	3.82	5.79
Not bearing	184.38	3.48	2.01	3.03
Total commercial	535.93	10.11	5.83	8.82
Total fruit	580.69	10.96	6.32	9 56
Total area of all crops	5,866.75	110.69	63.83	96.54
Total area of farms	9,191 06	173.42	100.00	....

The proportion of land occupied by obstructions in fields devoted to crops other than fruit, on farms of different sizes, is shown in table 24. With fruit crops very little land is made untillable by fences, open ditches, streams, or other causes, and the inclusion of land devoted to fruit would

TABLE 24. RELATION OF SIZE OF FARMS TO PROPORTION OF AREA OF CROPPED FIELDS OCCUPIED BY OBSTRUCTIONS

	Size of farms			
	Less than 100 acres	100–174.9 acres	175 acres or more	All farms
	Per cent of area of cropped fields occupied by obstructions			
Fence rows	2 42	1 78	1 79	1.84
Swampy land	0 87	0 92	0.31	0 55
Streams	0 63	0 38	0 45	0 44
Open ditches	0 20	0 38	0.16	0 23
Driveways in crop fields	0 49	0 23	0 13	0 20
Rough or steep land	0 43	0 28	0 08	0 17
Land shaded by woodlots	0.18	0 09	0 13	0 13
Trees in fields	0 02	0 02	0 15	0.10
Stone outcrops	0 16	0 01	0 01	0 03
Barns in fields	0 02	0 05	0 04	0 04
Stone piles	0.02	0 02	0 02	0 03
Total land in cropped fields occupied by obstructions (not producing a crop)	5.48	4.18	3 25	3 76
Land in cropped fields producing a crop	94 52	95.82	96.75	96 24

tend to obscure the effect of any factor on the proportion of crop land made untillable by these agents. The most important reason for the better utilization of crop land on the larger farms is that a smaller proportion of the crop area is occupied by fences. The larger fields of the large farms require less fence to the acre, and therefore less land is occupied by fence rows.

PASTURE LAND

Pasture land is intermediate in grade between crop land and woodland. In some parts of the State there are considerable areas of land which cannot be economically tilled but on which bluegrass or other pasture plants thrive. This land may be either too wet, too dry, too steep, too

stony, too distant, or of too heavy soil for economic crop production, or it may be bottom land subject to overflow. Such areas can generally be used best as permanent pasture. If the land is not suitable for pasture it should be put into a woodlot.

In other parts of the State nearly all of the land is tillable and can be farmed satisfactorily. Even in such regions there is some broken land along streams which can best be utilized as permanent pasture, but most of the tillable land is cropped. A few exceptional regions may be found where good tillable land is kept in pasture a large part of the time because it is peculiarly adapted to that purpose. Outside of these favored regions there is a tendency to keep little stock unless part of the land is suited only for pasture. In regions where practically all of the farm land is tillable, the farmers who keep stock often rotate pastures since by this practice more stock can be kept on a given area. Rotated pastures are usually better on light soils or with other conditions under which bluegrass does not thrive.

The classification of pasture land on the farms studied is shown in table 25. Pasture land classified as "Tillable" includes all land ready for cultivation which is as good as the land now in crops. The amount under "Could be made tillable" includes land which at reasonable expense could be made as good tillable land as that now under cultivation. In the case of "Woods pastured," it would of course be necessary to clear the land of trees.

Of the fifty-three farms here included, only three had no pasture land. All of these are located in western New York and kept little stock. Of the fifty farms having pasture, forty-five depended primarily on permanent pasture while five depended principally on rotated pasture. Nine of the forty-five farms depending primarily on permanent pasture supplemented this by some rotated pasture. All except one of these nine farms were intensive dairy farms. They had an average of 22.8 acres of rotated pasture, 92.3 acres of permanent pasture, and 30.5 cattle units, to each farm. Of the five farms depending primarily on rotated pasture, only two had more than six cows. They had an average of 18.1 acres of rotated pasture and 2.9 acres of permanent pasture to each farm.

The total pasture area occupied about 30 per cent of the area of these fifty-three farms, or 51.9 acres per farm. The 881.49 acres of woodland pasture was estimated by these farmers to furnish feed equivalent to

TABLE 25. CLASSIFICATION OF PASTURE LAND ON FIFTY-THREE NEW YORK FARMS

	Total number of acres	Number of acres per farm	Per cent of total farm area	Per cent of total pasture area
Permanent pasture:				
Cleared:				
Tillable:				
Lanes	17.46	0.33	0.19	0.63
Other land	200 46	3.78	2.18	7.29
Total tillable	217 92	4.11	2.37	7.92
Could be made tillable:				
Lanes	6.20	0 12	0.07	0.23
Other land	840 31	15 85	9.14	30.54
Total which could be made tillable	846.51	15.97	9 21	30.76
Not tillable	542.37	10.23	5 90	19.71
Total cleared	1,606 80	30 32	17.48	58.39
Woods pastured:				
Tillable if cleared	395 79	7.47	4.31	14.38
Could be made tillable	89.83	1.69	0.98	3.26
Not tillable	395.87	7.47	4.31	14.39
Total woods pastured	881 49	16 63	9.59	32.04
Area of cleared pasture to which woods pastured is equivalent	176 44	3 33	......	....
Total permanent pasture	2,488 29	46 95	27 07	90.43
Crop land temporarily pastured	263.33	4.97	2.87	9.57
Total pasture area	2,751 62	51 92	29.94	100 00
Area of cleared pasture to which total pasture is equivalent	2,046.57	38.61	22.27	74 38
Total farm area	9,191 06	173.42	100 00	....

176.44 acres of cleared pasture. The 51.9 acres of all pasture per farm was thus equivalent to 38.6 acres of cleared pasture, or 2.3 acres of cleared pasture for each cattle unit on these farms. Permanent pasture made up 90 per cent of the total pasture area. About two-thirds of the area

of the permanent pasture was cleared, but since it took about 5 acres of woods pasture to furnish as much feed as 1 acre of cleared pasture, the latter furnished about 90 per cent of the feed. Only a small part, one-seventh, of the cleared permanent pasture was then tillable, but more could be made tillable at reasonable expense. If conditions warranted, about two-thirds of the cleared permanent pasture land on these farms could be used for producing crops.

In general the selection of the pasture land on these farms followed the principles already discussed. The greater part of the pasture land was not adapted to crop production. In some cases this untillable pasture was supplemented by small areas of rotated pasture, consisting usually of the remoter crop fields. In general, the farms that had little or no untillable land kept little stock.

The location of the pastures on most farms is determined by the character of the land. Land that is not suited to crop production is used for pasture, whatever its location. Where the land of a farm is uniform and choice is possible, it is usually best to pasture the land that is remotest from the buildings. Long experience has proved that this plan is usually the best. The more conveniently located fields are worth more for cultivation, and labor is saved by pasturing the fields which cannot be farmed as advantageously. Distance from buildings is less important with pasture than with crop land, for where the barns and the pasture are connected by a lane the stock do most of the traveling. It is very advantageous, however, to have a night pasture convenient to the buildings. Altho this need not be as large as the day pasture, it should be large enough to furnish some feed.

Aside from interest and taxes, the principal cost in the upkeep of pastures is the cost of maintaining fences. Since the amount of fence to the acre is affected by both the size and the shape of the field, these factors are of some importance. The relation of the size of the field to the cost of fence maintenance is shown in table 26. Assuming that the costs of maintaining all pasture fence are chargeable to the pastures, at 6 cents a rod the cost of maintaining the fences around the 2-acre pastures in table 26 would be $2.45 an acre. This is as much as the usual rent of land worth $40 an acre. A considerable proportion of pasture land is worth only $20 or $25 an acre. Because of this, in regions where land is cheap small patches are often seen lying idle. On the basis of the

TABLE 26. RELATION OF SIZE OF PASTURES TO ECONOMY OF FENCING

Size of pasture fields (acres)	Number of fields	Average size of fields (acres)	Rods of fence to the acre	Annual cost of fence maintenance per acre at 6 cents a rod
Less than 4	29	2 07	40 8	$2.45
4–7.9	25	5 75	25.2	1.51
8–11.9	12	9 75	19 0	1.14
12–15.9	12	14.02	19 2	1.15
16–23.9	12	19.72	13 6	0.82
24–49.9	17	36.03	10.6	0.64
50 or more	13	84.46	6.4	0.38
Total	120	....	....	....
Average	... ...	20.30	11.8	$0 71

difference in cost of maintaining fences, the 84-acre pastures would be worth about $35 an acre more than the 2-acre pastures, since it costs $2.07 an acre less each year to keep the large pastures fenced. For these reasons, land that is to be pastured should be arranged in as large fields as possible. Usually part of the pasture fence is line fence, half of which is maintained by neighbors, and part may serve other purposes. An ideal pasture would be square, but the utilization of the different grades of farm land for the purposes to which each grade is best adapted is far more important than shape of the pasture. This factor, not economy of fencing, usually determines the shape of pasture fields.

WOODLAND

Woodland is the lowest grade of farm land. There are large areas in the country which are too steep or too remote, or on which the soil is too rocky or too poor, to produce economically any other crop than woods. To utilize land that is suitable for higher uses as woodland, is to put it in direct competition with the large areas which are suited only to timber production and on which timber can be produced at much lower cost. For these reasons farm woodlots should be located on land that is too rough, too steep, too poor, or too remote to be used economically for crop production or for pasture.

Much of the farm land of the State was originally cleared without due reference to topography or to the character of the soil. As a result many woodlots occupy level, rich, tillable land, while poor, barren hillsides, too steep for crops or even for good pasture, were cleared. In order to correct these mistakes in clearing, some readjustments were necessary. It did not take many years of experience to determine that some land had been cleared by mistake. Part of this land has already gone back into forest. More should go. On the other hand, the increasing scarcity of good land as reflected in higher prices has stimulated the clearing of some of the woodlots on the highest-priced land. As time goes on, this process may be expected to continue.

The proportion of woodland on the farms studied, and the purposes to which it is adapted, in the opinion of the writer, are shown in table 27. The woodland classed as "Tillable if cleared" would be approximately as good land as that now under cultivation. Woodland classed as "Could be made tillable" includes land which, after clearing, could be made tillable at reasonable expense either by drainage, by clearing of stone, or by other means. Woodland not tillable is divided into two classes, that which would make good pasture after clearing and that which is suited only for woodland.

Of the fifty-three farms included in this study, forty-three, or about four-fifths of the total, had woodlots. A larger proportion of the large farms had woodland. Of thirteen farms containing less than 100 acres, eight had woodlots; while of twenty containing more than 175 acres, all except one had some woodland. The average area of woodland per farm was 21.6 acres, or about 12 per cent of the farm area. The proportion of the farm area in woodland is less on the smaller farms than on the larger farms. On the smaller farms land is generally too scarce to be used for forestry purposes.

About half of the woodland on these farms, if cleared, would make as good tillable land as that now under cultivation, without additional expense. In addition to this, about one-seventh of the area of woodland could be made tillable at reasonable expense, after clearing. Most of the remaining woodland would make good pasture land if cleared. About 10 per cent of the total area of woodland on these farms is suited only for timber production.

TABLE 27. CLASSIFICATION OF WOODLAND ON FIFTY-THREE NEW YORK FARMS

	Total number of acres	Number of acres per farm	Per cent of total farm area	Per cent of total woodland area
Woodland pastured:				
Tillable if cleared	395.79	7.47	4.31	34.64
Could be made tillable	89.83	1.69	0.98	7 86
Not tillable:				
Suitable for pasture	297.09	5.61	3.23	26.00
Suitable only for woodland	98.78	1.86	1.07	8.65
Total not tillable	395.87	7.47	4.31	34.65
Total woodland pastured	881.49	16.63	9.59	77.15
Woodland not pastured:				
Tillable if cleared	151.89	2.87	1.65	13.29
Could be made tillable	64.33	1.21	0.70	5.63
Not tillable:				
Suitable for pasture	22.30	0.42	0.24	1.95
Suitable only for woodland	22.58	0.43	0.25	1 98
Total not tillable	44.88	0.85	0.49	3.93
Total woodland not pastured	261.10	4.93	2 84	22 85
All woodland:				
Tillable if cleared	547.68	10.33	5.96	47 93
Could be made tillable	154.16	2.91	1.68	13 49
Not tillable:				
Suitable for pasture	319.39	6 03	3 48	27 95
Suitable only for woodland	121 36	2 29	1.32	10 62
Total not tillable	440 75	8.32	4.80	38.57
Total woodland area	1,142 59	21 56	12 43	100 00
Total farm area	9,191.06	173.42	100 00	....

It should not be inferred from this that all of the woodland suited to crops or pasture should be cleared at once. Some of it should never be cleared. In deciding whether to cut or to leave a woodlot, the most important considerations are the value of the land for other purposes, and the kind of timber in the woodlot. Where land is moderately high in price it will seldom pay to leave good level tillable land in woods. Usually it will be best to cut the timber and gradually clear such land. It seldom

pays to reforest land worth more than $10 an acre, but it may pay to leave a growing stand of valuable timber until maturity on land worth more. Practically all of the farm land in New York State which will make good crop or pasture land is too valuable to be used for commercial timber production.

Farm woodlots are often justified on land that is too valuable for commercial forestry purposes. In producing fence posts, firewood, and lumber for home use, a farmer is saving himself the retail prices of these products. In selling lumber he must sell on a wholesale market. The saving between the retail and the wholesale prices of these products, and the saving in hauling both ways, will pay the interest on higher-priced land.

A few woodlots have value as windbreaks. While less important in New York State than on the western plains, a windbreak is very desirable for buildings located in an exposed position. This consideration is negligible on most farms, however, as the woodlots are not usually located so as to be of any use for this purpose. On the other hand, woodlots frequently injure adjacent crop land by their shade or by keeping the land too wet. The width of the strip of land wasted because of proximity to woodlots varies from 1 to 4 rods. On the farms included in this study, about 7 acres of crop land in fields adjacent to woodlots was thus wasted. This increases somewhat the expense of maintaining woodlots.

Most farms have more woodland than is needed for home use, and much of this woodland has little or no valuable timber. Where such land is suited to crops or pasture, it will usually pay to cut the timber in order that the land may be used for the purpose which pays best. Pasture is a more valuable crop than timber, and the returns from pasture are not so long deferred.

On these farms an average of 11.8 rods of fence was required to inclose an acre of pasture (table 26, page 493), and the annual cost of fence maintenance, at 6 cents a rod, would therefore be 71 cents an acre. If 2 acres of pasture will support a cow for the pasture season, and if the value of her pasture is $10, the returns from an acre will pay for fence maintenance, taxes, and interest at 6 per cent on a value of about $60 an acre. On the same basis, if 3 acres of pasture are needed to support a cow, the land is worth about $37 an acre as pasture; if 4 acres are needed for each cow, the land is worth $25 an acre; and if 5 acres are needed for

each cow, the land is worth $18 an acre. If more than 5 acres are needed to support a cow, it may be worth while to consider the possibilities of the land if it is allowed to remain in forest.

After the owner has decided to clear a woodlot, the question arises as to whether it should be cleared at once or pastured until the stumps rot. In deciding this point, it is necessary to consider how great is the need for the land, how good pasture it will make, the cost of clearing, and how near the land is to the buildings. Often, if land is needed at once, cleared land can be bought more cheaply than woodland can be cleared. Clearing land at once puts today's high-priced labor in competition with the cheaper labor of the past, when most of the land was cleared. Usually pasture land is needed, and such cut-over land can be pastured to good advantage until the stumps rot. This usually requires from ten to twenty years and then the land can be cleared cheaply.

About four-fifths of the woodland on the farms studied was pastured. Most of the woodland which was not pastured was either not convenient for pasturing or not worth pasturing. Undoubtedly pasturing injures woodlots to some extent. Where land is worth $20 or more an acre as pasture, the more important question is as to whether woods should be allowed in the pasture. Five acres of woodland pasture was considered equivalent to one acre of cleared pasture on these farms. It is well to have some trees in a pasture, to provide shade. Pasture in open woods is often as good as cleared pasture. It may be possible to produce wood and posts for home use by this arrangement without serious injury to the pasture.

The plan of a western New York farm is shown in figure 131. The location of the woodlot V, on level, tillable land near the buildings, is typical of many farms. Such land is too valuable for forestry purposes. Cleared tillable land in this region is worth $100 or more an acre. While this large area of level, tillable land has been left in woods, many fields far from the buildings have been cropped. Field R, which has been cropped regularly, is 188 rods farther from the buildings than woodlot V. For general farm purposes, with 1918 labor prices, field V would be worth from $30 to $35 an acre more than field R, on the basis of location alone. It is also better land. Field R is but a few rods from a neighbor's barn, but it is 234 rods away, uphill, from the barn of the man who farms it.

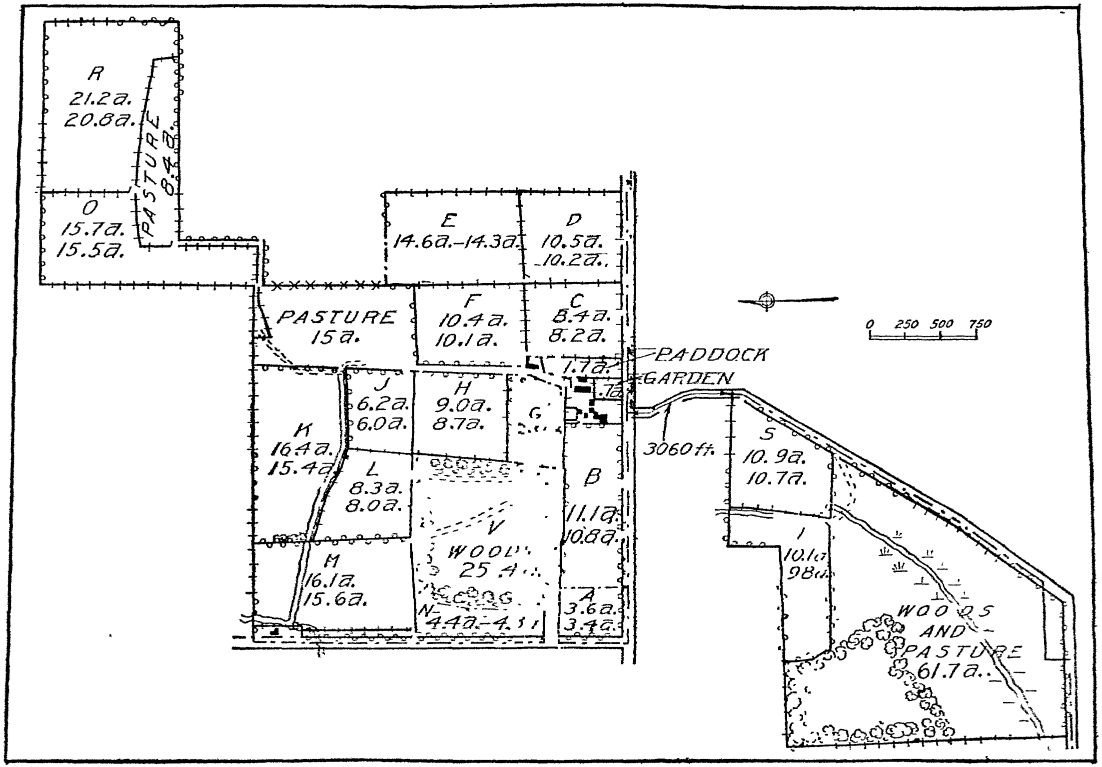


FIG. 131. UNECONOMIC WOODLAND ON A WESTERN NEW YORK FARM

The woodlot V occupies level tillable land near the buildings and worth $100 an acre if cleared. This is a large farm with relatively small fields, many of which are of undesirable shape. It could be easily and cheaply rearranged by taking out some unnecessary fences and tiling one open ditch

Farm area, 306.2 acres
Average size of farmed fields, 10.4 acres
Average distance to farmed fields, 118 rods

The plan of another western New York farm having a woodlot located on good tillable land is shown in figure 132. On this farm the woodland is being gradually cleared for cultivation as opportunity offers. In this case the land is being cleared at once, without waiting for the stumps to rot. During 1916 and 1917 about two acres of land on the north and east sides of the woodlot were added to the cultivated area. In a few years the entire woodlot will be cleared and under cultivation. Crop land here is worth $125 an acre.

These readjustments in the utilization of woodland will not come in a day. In addition to the owner of the farm shown in figure 132, four other farmers out of the forty-three having woodlots have definitely planned to clear them for cultivation. On some of these farms the timber has already been cut. On most of them the stump lots will be pastured for a term of years before final clearing. The farmers having high-priced land are naturally the first ones to begin clearing woodland. The present high price for firewood is enabling some farmers to make wages cutting woodland which has no valuable timber, and so is stimulating the process. As population increases and the consequent scarcity of land relative to population is reflected in higher land prices, the area of crop land in New York will be considerably increased in this way.

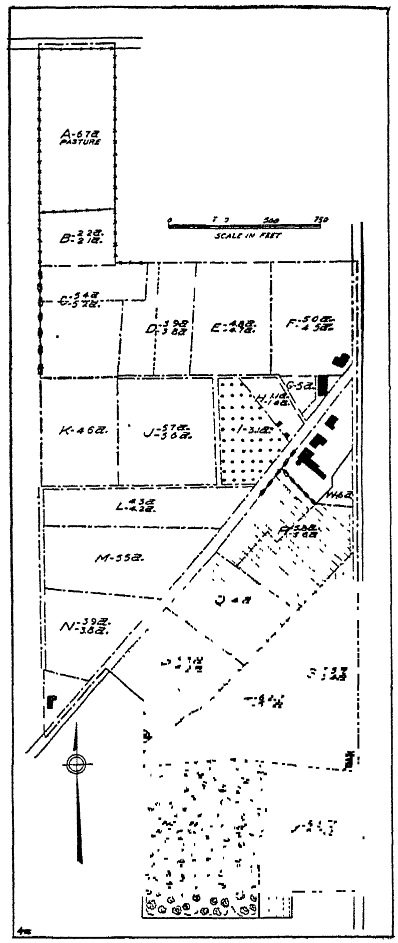


FIG. 132. ANOTHER UNECONOMIC WOODLOT OCCUPYING TILLABLE LAND TOO VALUABLE FOR TIMBER PRODUCTION

This woodlot is being gradually cleared for cultivation, the work being done in slack periods. Nearly all of this farm south of the road was originally swampy pasture. It was reclaimed for cultivation by a complete system of tile drains. Only valuable crop land would be worth reclaiming at such expense. Small fields are necessary on this farm as the land is largely devoted to truck crops

Farm area, 108.4 acres
Average size of farmed fields, 4 acres
Average distance to farmed fields, 52 rods

PUBLIC HIGHWAYS

In most parts of New York State the owner of a farm holds title to the land in the adjacent highway, the only right of the public to the latter being the right to its free and uninterrupted use for highway purposes. The area of a farm as given in the deed therefore usually includes the area of all roads running thru the farm and one-half the area of roads bounding the farm. While land in highways is technically owned by the owners of adjacent farms, little of this land is used for producing crops and so it adds nothing directly to the farm income. However, the importance of good roads is so great in economic farm operation that the land necessarily occupied by good, well-planned roads is one of the most valuable assets of a farm.

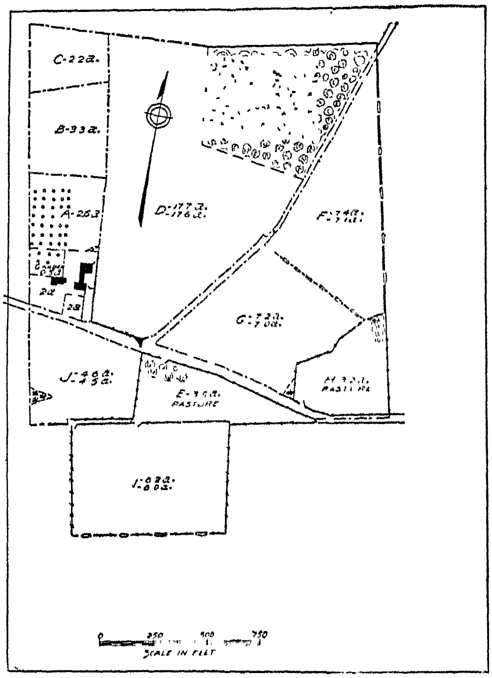


FIG. 133. PLAN OF A SOUTHERN NEW YORK FARM

The crooked highways which cross [illegible] use the irreg[illegible] The [illegible] the right of way of the highway is 5.1 per cent of the farm area. Part of the roadside is cropped, the area of the highway not in crops being 3.7 per cent of the farm area

Farm area, 72.7 acres
Average size of fa[illegible] acres
Average distance to [illegible], 35 rods

In that part of the State which was settled last, much of the land was laid out in squares, with straight roads in so far as topography permitted. Since this section is relatively level, the highways as a rule are straight. In the eastern and southeastern parts of the State, which were settled first, the roads were not planned, but developed, like the farm layouts, largely by chance. In general the roads tend to follow the topography of the land, avoiding the steepest grades. Even where there are no grades to avoid, many of the highways are crooked (fig. 133). The most serious effect of these crooked roads on farm

layout is that they divide many farms into irregularly shaped parts which are inconvenient to work and difficult to fence.

The amount of land in highways on the farms studied is shown in table 28. The average area of highways per farm was 3.13 acres, or 1.8 per cent of the total farm area. Apparently size of farm has little effect on the proportion of the area in highways. On farms of less than 100 acres

TABLE 28. LAND IN HIGHWAYS ON FIFTY-THREE NEW YORK FARMS

	Total number of acres	Number of acres per farm	Per cent of total farm area	Per cent of area of legal right of way of highways
Land in highways not cropped	144.75	2.73	1.57	87.19
Land in highways cropped:				
General crops	16.57	0.31	0.18	9 98
Apple trees	4.69	0.09	0 05	2.83
Total land in highways cropped	21 26	0 40	0 23	12.81
Total land in highways	166.01	3 13	1.81	100.00
Total farm area	9,191.06	173.42	100 00	...

the proportion of the farm area in legal right of way of highways was 1.8 per cent, on farms between 100 and 175 acres in size it was 2.1 per cent, and on farms of more than 175 acres it was 1.7 per cent. There was considerable variation for the different farms, the proportions varying from 0.4 to 5.1 per cent. In the purchase of a farm the proportion of the area occupied by roads is of some importance, as every acre so used reduces by that amount the productive area of the farm.

About one-eighth of the total area of highways on these farms was producing crops. In a few cases apple trees were planted along the highway, thus utilizing land that would otherwise have produced only weeds. The principal disadvantages of this way of utilizing roadsides is the inconvenience of spraying and taking care of a single row of trees. Further, while the fruit as well as the land belongs to the farmer as much as does any crop on his farm, he will probably harvest a smaller proportion

of it because of its convenience to travelers. The greater part of the area of the roadside cropped on these farms was in general crops. On some farms road fences were not maintained and the fields were tilled to the road ditch, all the land not actually occupied by the road being thus utilized.

The usual width of a country highway in New York is 3 rods, but occasional highways are 4 or even 5 rods wide. The public has the right to free and uninterrupted use for highway purposes of such a proportion

Fig. 134. A stone row which renders useless an acre of land worth $100
By clearing away these stones a strip of land 2 rods wide could be added to the adjoining field

of this land as is necessary for the traffic. The actual width of a well-graded dirt road is very seldom more than $1\frac{1}{2}$ rods, while the width of macadam roads is usually less than 2 rods. The traveled area of many country roads is less than 1 rod in width. Where the roads are fenced, the balance of the right of way is usually covered with grass, weeds, and brush. The state highway law requires each property owner to mow his roadsides twice each year. They are usually mowed once; but the hay obtained is dusty and of very poor quality. Most farmers would be glad if some one would mow their roadsides for the hay. In other words, the roadsides of most farms are worse than merely useless, since constant expense is necessary to keep the weeds down. Road fences are

no longer obligatory in New York, as stock running loose on the highway is regarded as trespassing. Consequently, where road fences are unnecessary, their removal would result in a twofold saving. Not only would a considerable area be added to the crop land, but the labor of mowing roadsides would be saved (figs. 134 and 135). Such a change would not interfere in any way with the usefulness of the roads as highways and would improve the appearance of the roadsides. Certainly a road bordered by well-cared-for crops presents a far more attractive appearance than one bordered by brush and weeds.

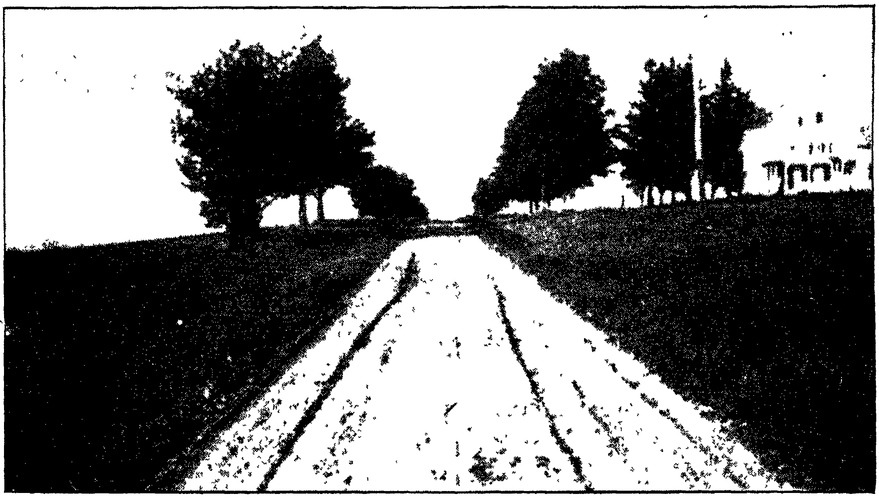


Fig. 135. WHERE ROAD FENCES ARE UNNECESSARY THEIR REMOVAL PERMITS FARMING TO THE ROAD DITCH

This road occupies less than a rod of land

On these farms about 21 acres have already been added to the crop area by reclaiming useless roadsides. By eliminating unnecessary road fences about 30 acres more could be added to the land in crops. The width of the strip of land gained depends on the width of the road and the topography of the land. Where the road is of ordinary width and is not bordered by steep banks, a strip of land from ½ to 1 rod wide can usually be added to the crop land on each side.

The question of fencing roadsides depends primarily on the stock kept on the farm. It is of course necessary to fence pastures bordering on the road, and where much stock is kept it is frequently profitable to fence some crop fields in order to pasture the aftermath. In New York it seldom pays to fence against stock driven along the road. The average length of roadside on these farms was 324 rods, 62 per cent of which was fenced. The proportion of roadside fenced varied for all the farms, from 52 per cent on the farms of less than 100 acres, to 72 per cent on farms of more than 240 acres. Many road fences are barriers only to cultivation, being of no use whatever in turning stray stock. Where such useless or unnecessary fences can be removed at a reasonable cost, the double saving of land and labor will usually justify the expense.

THE FARMSTEAD

The farmstead, as the term is here used, is that part of the farm which is occupied by the main group of farm buildings, together with any adjoining yards or paddocks, the home orchards, and the home garden. A part of the area of every farm must be devoted to these purposes, the size of the necessary area depending on the size of the farm, the type of farming, and other factors. Aside from the orchard, the garden, and the paddocks, every acre devoted to use as farmstead reduces by that amount the productive area of the farm. Land necessarily occupied by well-planned buildings is usefully employed and adds to the value of the farm. Since the farmstead usually occupies the best tillable land, it is essential that it be well planned in order to make the best use of land as well as of labor.

The location of the farmstead with reference to fields has already been discussed. The ideal location for a farmstead is on a public road in the center of the crop area. With farms of small or moderate size it is best to locate the farmstead as near the center of the crop land as it can be placed and still be on the road. With very large farms the importance of saving labor in travel to and from fields is so great that it is best to locate the farmstead at the center of the farm.

While it is advantageous to have reasonably close neighbors, it is not usually preferable to have them directly across the road. The neighbor's children, dogs, and chickens will give less trouble if the houses are some

distance apart. It is a distinct advantage to own and control both sides of the road.

The ideal location for a farmstead is on a slight elevation, sufficient to give good drainage but not enough to make hauling difficult. Altho less important in New York than in the West, it is advisable to have the farmstead sheltered from strong prevailing winds by a windbreak.

Frequently the buildings of a farmstead are on both sides of the road, the house being on one side and the barns on the other. This arrangement is usually bad. There is great danger of injury to persons and stock by automobiles running between the house and the barn. The barns and the necessary implements near by do not make an attractive view either from the front windows of the house or from the road. The house should be located far enough from the road to escape the dust but not far enough to make too large a lawn. The distance from the house to the edge of the road on the farms studied varied from 30 to 160 feet, averaging about 65 feet. Where the distance was greater than 100 feet the lawns were not usually well kept. The best location for the barn is at a convenient distance behind the house. With such an arrangement the piles of lumber and the necessary tools can be kept out of sight from the road, and this location is preferable from every point of view.

The utilization of the land in farmsteads on the farms included in this study is shown in table 29. The average size of the garden area included in the farmsteads of these farms was about one-third of an acre to each farm. Three farms had gardens in crop fields which were not included in the table. Including these, the area of garden to each farm was about 0.4 acre. Forty-seven out of fifty-three farms had gardens large enough to be recognized as such. Of the six farms having no garden, three were truck farms and hence needed none. In addition to the definite garden area, most farmers grew potatoes in the crop fields for home use.

The farm garden should be one of the most profitable enterprises on a farm. By proper arrangement, little more time is required to take care of the garden than to take care of a similar area in potatoes or corn. Since garden work conflicts with work on crops, the garden should be arranged to save labor. It should be located near the house for convenience in working. The area necessary depends on the size of the family. In this study, on the farms where the family consisted of the equivalent of three adults the average size of garden was 0.3 acre; on those where

the family consisted of the equivalent of more than three but less than five adults, the average size of garden was 0.4 acre; and on those where the family consisted of the equivalent of five or more adults, the average size of garden was 0.6 acre. This is an average of about 0.1 acre of garden to each adult person or equivalent.

TABLE 29. LAND IN FARMSTEADS ON FIFTY-THREE NEW YORK FARMS

	Total number of acres	Number of acres per farm	Per cent of total farm area	Per cent of total farmstead area
Farmstead crops:				
Home garden:				
Separate garden	15.98	0.30	0.17	9.80
Garden in orchard	2.35	0.04	....	....
Total home garden	18.33	0.35	....	....
Home orchard:				
Apple	40.54	0.76	0.44	24.87
Mixed fruit	2.90	0.05	0.03	1.78
Total home orchard	43.44	0.82	0.47	26.65
Other farmstead crops	2.63	0.05	0.03	1.61
Pasture:				
Paddock	12.69	0.24	0.14	7.78
Pasture in orchard	17.16	0.32	....	....
Total farmstead pasture	29.85	0.56	....	....
Land occupied by buildings, lawns, barnyards, drives, etc.	88.28	1.67	0.96	54.15
Total farmstead area (less double cropping)	163.02	3.08	1.77	100.00
Total farm area	9,191.06	173.42	100.00	....

The average size of home orchards was about 0.8 acre to each farm. Thirty-two farms out of the fifty-three had separate home orchards. Of the twenty-one farms not having home orchards, nineteen had commercial orchards from which fruit for home use was obtained, and the other two were in regions where apples do not thrive. The average area of home orchards for the farms having such orchards was 1.36 acres. More than

90 per cent of the area of home orchards was in apples, the remainder being devoted to mixed fruits.

The average area in paddocks for all farms was 0.24 acre. Only eleven farms out of the fifty-three had such farmstead pastures, and the average area of paddocks for these farms was 1.15 acres. Barnyards which afforded no pasture were not included in this classification, but were considered as land occupied by buildings and yards. In lieu of other paddocks, eight farms used the home orchards for this purpose, this being an average of about 2.15 acres for these farms, or 0.32 acre for all the fifty-three farms. All the farms pasturing orchards were located in regions where apples are a very uncertain crop. By pasturing such orchards some return is secured every year, and occasionally some apples are obtained in addition. Where hogs or cattle are kept it is advantageous to have small paddocks or pastures close to the buildings. These may be used for calf, hog, bull, or horse pastures, as the case may require. If land is not too limited, the saving in labor effected by the use of such pastures will often amount to good rental for the land so used.

The area of land occupied by buildings and yards averaged 1.67 acres to each farm (table 30). This included the lawns and barnyards as well as the actual building sites. The lawns on these farms ranged from nothing up to about one-half acre. A few farmers had their gardens in their front yards. Lawns more than half an acre in size are seldom found on the farms of men who make their living from the soil.

Far more important than the waste of good land is the fact that a large area of land occupied by buildings usually indicates scattered buildings and a resulting waste of labor in doing work. The plan of a farmstead with scattered buildings, requiring much unnecessary travel, is shown in figure 136. Several hundred miles of walking would be saved every year with well-arranged, concentrated buildings. Altho fire risk is somewhat greater, fire insurance is cheaper than wasted labor and materials in scattered, inconvenient buildings. The barns must be at least 100 feet from the house if the lowest insurance rates are to be obtained. This is usually far enough so that unpleasant barn odors may be avoided, and any increase in distance beyond this sacrifices some labor. On the farms studied, the average distance from the house to the nearest door of the horse barn was about 130 feet and to the nearest door of the cow barn about 200 feet.

TABLE 30. RELATION OF SIZE OF FARMS TO AREA AND PROPORTION OF LAND IN FARMSTEAD

	Size of farms (acres)							
	Less than 100	100 to 174.9	175 or more	All farms	Less than 100	100 to 174.9	175 or more	All farms
	Acres per farm				Per cent of farm area			
Farmstead crops:								
Home garden:								
Separate garden.....	0.21	0.35	0.31	0.30	0.28	0.27	0.11	0.17
Garden in orchard....	0.08	0.05	0.02	0.05	......	......	......	......
Total home garden..	0.29	0.40	0.33	0.35	......	......	......	......
Home orchard:								
Apple.............	0.27	0.66	1.20	0.76	0.36	0.52	0.42	0.44
Mixed fruit..........	0.11	0.06	0.01	0.06	0.14	0.05	0.01	0.03
Total home orchard.	0.38	0.72	1.21	0.82	0.50	0.57	0.43	0.47
Other farmstead crops...	0.07	0.02	0.07	0.05	0.09	0.02	0.02	0.03
Pasture:								
Paddock	0.18	0.11	0.41	0.24	0.24	0.08	0.15	0.14
Pasture in orchard.	......	0.28	0.58	0.32	......	......	......	......
Total farmstead pasture.........	0.18	0.39	0.99	0.56	......	......	......	......
Land occupied by buildings, lawns, etc..	1.52	1.41	2.02	1.67	1.99	1.11	0.71	0.96
Total farmstead (less double cropping)	2.36	2.61	4.02	3.08	3.10	2.05	1.42	1.78
Total farm area...... ..	76.22	127.36	282.65	173.42	100.00	100.00	100.00	100.00

The average size of the farmsteads on these farms was 3.08 acres each, or 1.78 per cent of the total farm area. A little less than one-half — 46 per cent — of the total area of the farmsteads was producing some crop, either as garden, orchard, paddock, or otherwise.

The location and the arrangement of most farmsteads are fixed. Since in many cases farmsteads have developed without a definite plan, many of them are not well adapted to present conditions. In spite of this, it seldom pays to make revolutionary changes because of the expense involved. In some cases when farms are combined, the location and the arrangement of the farmstead are so bad that it would pay to plan a new farmstead in a convenient location. Usually, however, changes should be gradual. After a careful study of the farm conditions, a long-time plan for the farmstead and building development should be made.

Gradually, as conditions may justify, changes may be made in accordance with this plan, so that in a reasonable length of time a farmstead will be developed which is well planned and is adapted to existing conditions.

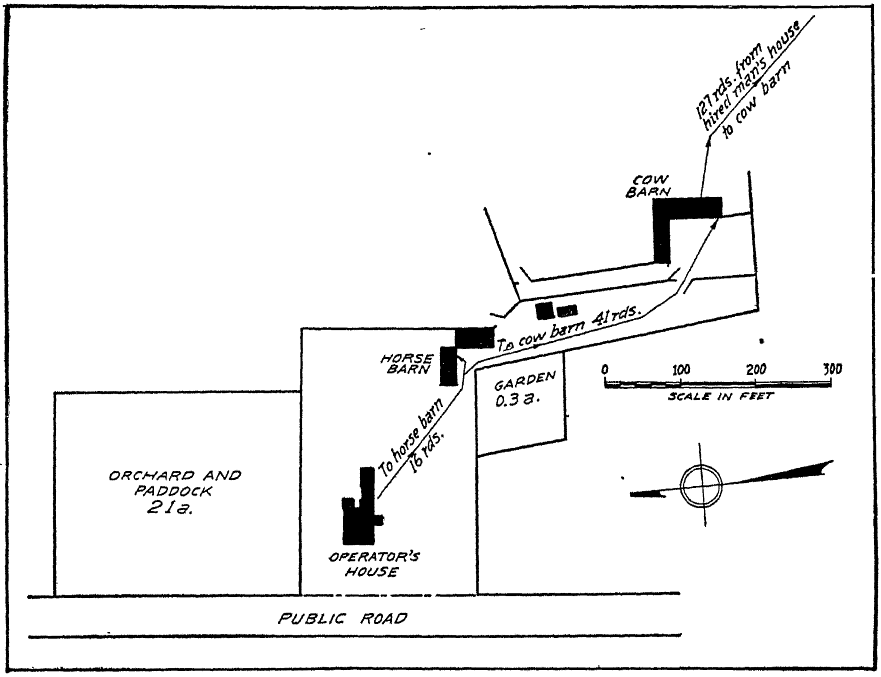


FIG. 136. AN ARRANGEMENT REQUIRING MUCH UNNECESSARY TRAVEL

The area of land occupied by the buildings of this farmstead is 2.82 acres, or 1½ per cent of the farm area More than 700 miles of walking would be saved yearly if the cow barn were 500 feet nearer the house

Two well-planned farmsteads are shown in figure 137. Plan I represents the farmstead of a western New York fruit and general farm. Both the owner's house and the tenant house are near the barns, and yet the houses are far enough apart to enable two ordinary families to live harmoniously. Both houses are perhaps located a little too close to the road, but since this is a concrete highway there is little dust. The area occupied by buildings is 1.22 acres, or 1 per cent of the farm area. The barns, rearranged in 1915 by the present owner, are centralized in order to save time in doing

the chores. Plan II represents the farmstead of a western New York general farm. Here, also, labor is saved by having both the owner's house and the tenant house convenient to the barns, and the barns centralized. The owner's house and the tenant house are separated by a part-

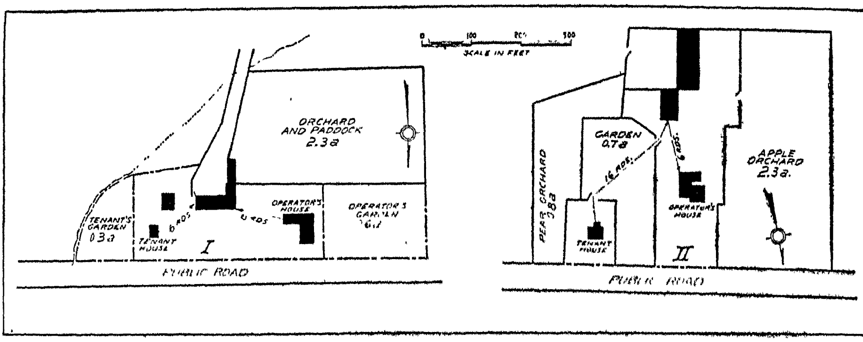


FIG. 137. TWO WELL-PLANNED FARMSTEADS

nership garden, while two orchards furnish an abundance of fruit for home use and some for sale. The area occupied by the buildings of this farmstead is 1.84 acres, or 0.9 per cent of the total farm area. Altho not ideal, both farmsteads are conveniently arranged and well adapted to their respective conditions.

TENANT HOUSES

Many of the present New York farms are combinations of two or more original farms or parts of farms. Usually each part of the present farm has separate buildings, and, since two farmsteads were unnecessary after combining, the extra house has in many cases been used as a tenant house for the hired man. In some cases inconveniently located houses have been moved to a convenient location near the main farmstead. On many farms tenant houses are still found in their original location, far from the main farmstead and causing the waste of much time in useless travel.

From the standpoint of labor efficiency, tenant houses should be located as near the main farmstead as possible because many trips must be made daily from the hired man's house to the barns. Of course the tenant house should not be too near the barns. A distance of 100 feet is necessary to satisfy insurance regulations.

In order that the two families may live in harmony, it is advisable that the tenant house be located not too close to the owner's dwelling. Each family wishes a certain amount of privacy in its domestic life, but with adjoining houses this is impossible. If the two houses are 20 rods apart both families will be happier and they will be better neighbors.

The location of the tenant houses shown in figure 137 illustrates very satisfactory compromises of these conflicting specifications. Privacy of the two families is secured in each case without sacrifice of convenience.

A striking contrast to these farms is presented by the arrangement shown in figure 136 (page 509). The tenant house on this dairy farm is located 127 rods from the cow barn. The hired man makes three round trips daily on week days and two on Sundays, and in doing this he travels 810 miles a year between his home and the cow barn. When walking is bad across the fields, his trip is longer. If the tenant house were located 100 feet from the barn, less than 40 miles of walking in a year would be necessary. To walk the extra distance necessary with the present location, at an ordinary speed of three miles an hour, would require 257 hours, or nearly twenty-six days. At \$2.25 a day the time wasted in useless travel amounts to \$58 a year. This tenant house is valued at \$400. If it could be moved to a convenient location for \$400, the time saved would pay about 15 per cent interest on the investment. While not all of this traveling is done during working hours, the farmer nevertheless pays for it all in lowered efficiency of the man. A hired man working hard every day does not need any such amount of additional exercise.

In this particular case the hired man's wife milks twice daily, as is the custom in southeastern New York. In her two round trips daily the hired man's wife walks 571 miles a year. The two thus walk 1381 miles a year between their house and the barns. Probably the wife gets no extra compensation for her additional exercise, so that it involves no direct financial outlay. It is quite certain, however, that a conveniently located tenant house would go a long way toward settling labor troubles on this farm and would prove an excellent investment for the owner.

Another inconveniently located tenant house is shown in figure 138. The distance from the tenant house A to the cow-barn door is 140 rods. At present a milking machine is used on this farm, and so the hired man does not milk in the mornings. He thus makes two round trips daily, or 630 miles a year. At \$2.50 a day the time thus spent would amount

to $52.50 a year. Half of these trips come out of the operator's time directly. The other half he pays for indirectly, perhaps unconsciously. Such a walk would be recreation to a factory worker or a clerk, but to a man who works hard at physical labor all day it is a part of the day's work. Probably this tenant house would be worth $500 or $600 more if it were located in the orchard near the main farmstead.

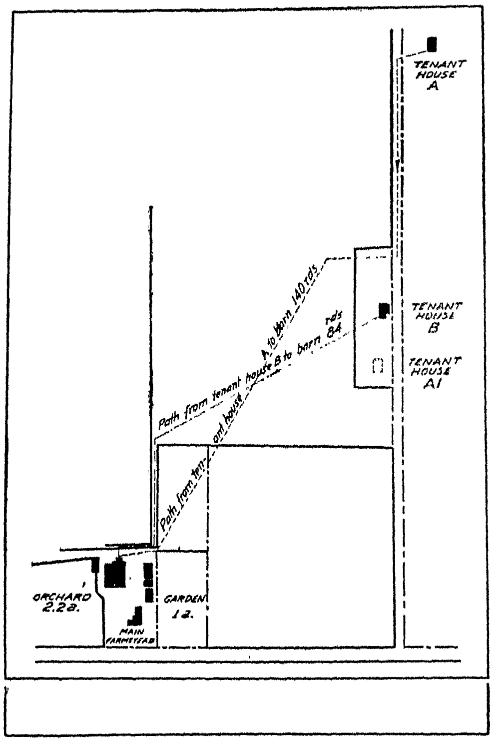


FIG. 138. PLAN SHOWING IMPROVEMENT IN LOCATION OF TENANT HOUSE

The hired man on this farm formerly lived in tenant house A, 140 rods distant from the main farm buildings. This location necessitated a minimum of 630 miles of walking yearly between the tenant house and the barn. In 191[illegible] the owner purchased the intervening farm and the hired man moved into tenant house B. This location is 56 rods nearer the barn and saves at least 250 miles of walking, or about 80 hours, in a year

The owner of this farm recently bought the small intervening farm, on which is located tenant house B. The distance from here to the cow-barn is 56 rods less than from tenant house A. With two trips a day this location would save 252 miles of walking in a year and perhaps $21 worth of time. The owner plans to move tenant house A to the location indicated as tenant house A¹. This location is surely sufficiently remote from the main farmstead.

On the farms included in this study, the average distance from tenant houses to their respective farmsteads was 72 rods. Assuming a minimum of two round trips daily, this distance means 324 miles of travel in a year. A distance of 20 rods would be much better.

Of the fifty-three farms studied, thirty-two had one or more tenant houses, the total number of houses being forty-five. Forty-two of the

forty-five tenant houses had gardens, the average size of garden being 0.3 acre (table 31). In addition to a garden, eighteen of the hired men were furnished potatoes from the farm crop. The size of gardens ranged from 0.1 acre to 1.2 acres. Where hired men are given large gardens they are

TABLE 31. TENANT HOUSES ON FIFTY-THREE NEW YORK FARMS

	Area occupied by 45 tenant houses (acres)	Average area occupied by each tenant house (acres)
Gardens	13.28	0 30
Orchards	1.32	0 03
Land occupied by buildings	19.64	0 44
Total area	34.24	0.76

not usually furnished potatoes for winter use in addition. The area of land necessary to grow the potatoes furnished to the hired men was about 4.6 acres, or an average of 0.1 acre to each tenant house. Only two of the forty-five tenant houses had separate orchards for the hired man's use. On most farms the hired man is given such fruit as the farm produces, but does not have a separate orchard.

On most farms not enough attention has been paid to the location and arrangement of tenant houses. The house should, of course, be comfortable. The garden should be ample in size, usually from half an acre to an acre. Few hired men will leave a good garden in midsummer. A little care and attention in these matters will make for more efficient work and better-satisfied hired men. In times of labor shortage these considerations gain added importance.

RELATION OF FARM LAYOUT TO OTHER FACTORS

The preceding discussions give some of the specifications for an ideal farm layout, but the layout of most farms is far from ideal. Farm layouts have developed, not according to a well-laid plan, but largely according to chance, and as a result they are not adapted to present conditions.

The farm plans included in these pages illustrate, in the main, all the undesirable features of farm layout and few of the good features. And yet these are the plans of prosperous farms, larger, better organized, and more profitable than the average New York farm. Some of these farms never were well arranged. Others were once well arranged, but changes in their area or in agricultural conditions have made them unsuited to present conditions. Only a few of them, indeed, are even reasonably well arranged to meet present conditions. It is therefore evident that the main problem of farm layout is the problem of rearranging farms to meet conditions of the present day and of the probable future.

On most New York farms it would not be possible to make an arrangement that would satisfy all the requirements of an ideal farm layout. There are natural limitations which prevent many farms from ever having even a moderately good layout. Perhaps the most important of these natural limitations is topography. Given fairly fertile land, its topography usually determines whether it shall be cropped or pastured. If it is too steep for machine operation, it must be pastured. In the hilly parts of New York it is necessary to crop all the land that is level enough. The field lines of such farms, therefore, follow the contour lines, and small, crooked fields are the usual result. Since topography cannot be altered, the shape and the size of fields on many farms are limited by this factor.

Soil differences limit the development of farm layout to some extent. It is preferable to have all the soil in one field fairly uniform. In most cases the differences in soil between adjoining fields are not great enough to make this factor important. Differences in drainage also are important in combining fields. All the land in a field should have uniform drainage, otherwise the whole field must wait for the wet land to dry. The drainage can be made uniform in many cases by tiling wet areas.

HOW TO PLAN A FARM REARRANGEMENT AND FOLLOW OUT THE PLAN

In spite of natural limitations it is possible and practicable to greatly improve the layout on nearly all farms. There is no one particular layout to fit all cases. Every farm presents an individual problem which must be studied and considered separately.

The first step in planning a rearrangement is to study the farm and the conditions surrounding it. For this purpose it is well to have a map of

the farm. This need not be an engineer's map, accurately drawn to scale; a rough plan showing the relative sizes, shapes, and locations of the various fields will serve. The more accurate the map, the worse, usually, will it make the farm look. In addition to the map, it is necessary to have a thoro knowledge of the soil and drainage conditions, and of the topography of the different parts of the farm.

The second step in planning a rearrangement is to decide on the cropping plan or rotation that is to be followed. While it is not possible to follow a rigid crop rotation on most farms, it is advisable to follow a fairly definite cropping plan. Knowing the crops that are to be grown, the acreage needed for each, and the crop area, a cropping plan can be made which will satisfy these requirements. If two rotations are followed, two sets of fields, perhaps of different sizes, will be required.

After studying the farm and deciding on the system of farming and the crop rotation to be followed, plans should be made for the long-time development of the farm which will provide as good a layout as the natural limitations will permit. The plans should be developed slowly and the work should be done at odd times. The savings to be made are seldom large enough to pay the entire cost in one year. If properly planned, such work helps in the labor distribution by keeping the men profitably employed when there is little other work to be done. Small fields can gradually be combined into larger units without radical changes in the rotation. It is usually unnecessary and unwise to plow up a good new seeding in order to combine two fields; the same results might be accomplished in a year or two by repeating a crop on one of the fields, or by leaving down a piece of hay for another year.

In buying a farm the layout is worthy of careful consideration. Before buying, a map or rough plan of the fields should be made, indicating the area and the important natural features of each.

ACTUAL REARRANGEMENTS OF SOME NEW YORK FARMS AS MADE BY OWNERS

While on most farms the rearrangement of the layout to meet conditions of the present day has received little attention, on some farms such changes have been and are being made. A few of these rearrangements are described in the following pages.

REARRANGEMENT OF TWO CENTRAL NEW YORK FARMS

The first farm

In figure 139 is shown the plan of three central New York farms as existing in 1914. These farms were owned at that time by one man but were

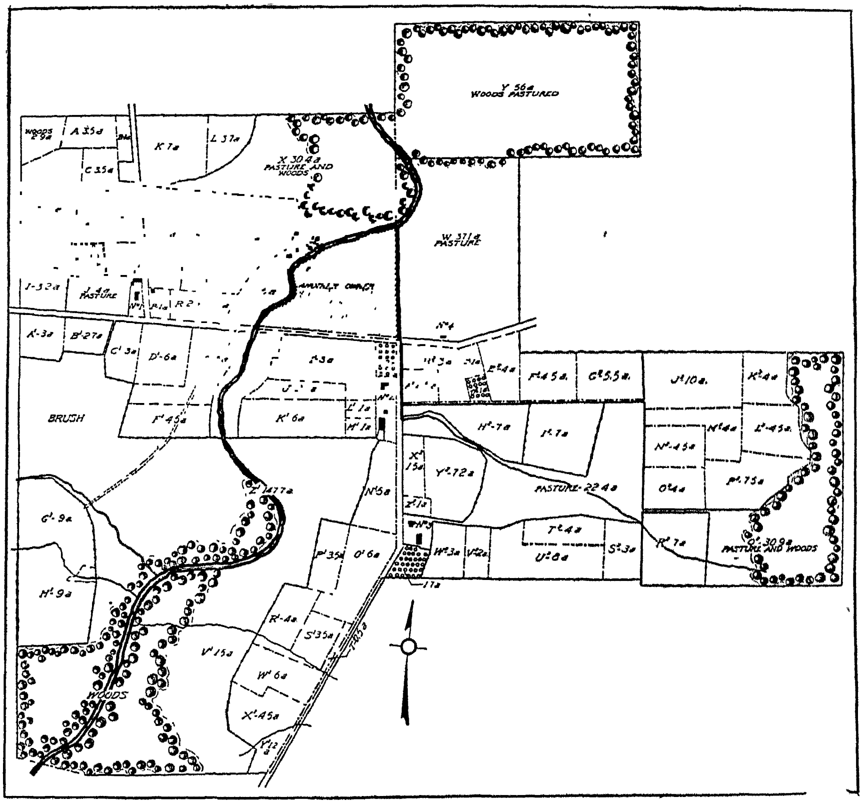


FIG. 139. PLAN OF THREE CENTRAL NEW YORK FARMS AS OPERATED IN 1914

The tillable land of these farms was divided into sixty-four small fields, averaging 4.3 acres each

Farm area, 646.4 acres
Average size of farmed fields, 4.3 acres

run as separate units, two being rented and the third being operated by the owner. The topography of the section is rolling, a considerable proportion of the farm areas being in untillable permanent pasture. The important crops grown are silage corn, cabbage, hay, oats, potatoes, and

buckwheat. Dairying is the most important enterprise. Milk, cabbage, hay, and buckwheat are the principal products sold.

These farms were excellent examples of patch farming, the tillable land being divided into sixty-four general crop fields averaging 4.3 acres each. On the three farms there were in 1914 a total of eight patches of corn, nine of oats, thirty-eight of hay, two of millet, two of cabbage, four of potatoes, and one of buckwheat. Some of these patches were farmed together when in hay, but the land had been plowed in the sixty-four fields shown on the map. There was no particular reason why these farms should be worked in such patches, except that they always had been farmed that way. Practically the only interior fences were the pasture fences, which were made irregular by natural conditions of topography and drainage. Fields J^2, K^2, L^2, M^2, N^2, O^2, and P^2 had never been manured, to the knowledge of the present owner. Fields G^1 and H^1 had been manured but once.

The field marked "Another owner," in the center of these farms, belongs to and is farmed by a farmer living more than a half mile away. The owner of this patch continues to farm this land at such a disadvantage, rather than trade it for a like area of land adjacent to his buildings, having refused such an offer from the former owner of these farms.

In the spring of 1915 these farms were purchased by their present owner, who was able to make only a small payment and gave a mortgage for the remainder of the purchase price. He worked the entire area as one farm, but he used all the farmsteads. Farmstead 2 was the real center of farm operation because it was the one most centrally located. The cows were kept here and the house was occupied by one hired man. The house at farmstead 1 was occupied by the owner, who kept his team and some young stock in the adjoining barns. The house at farmstead 3 was occupied by another hired man, who kept his team in the barn adjoining. The fourth house was used for the other regular hired man. By this plan of operation some of the disadvantages of the large area were overcome. Each worker had his team convenient to his house, and, when choice was possible, worked in the fields that were the most convenient. All the men helped with the milking at the main farmstead, but the young stock were located at one of the other two barns. Hay for sale was drawn to the most convenient barn. Oats were threshed from the two barns where the straw was needed.

Before starting spring plowing the first year, the new owner had decided on a plan of rearrangement and had the work on it well under way. The

development of the plan has been progressing slowly each year up to the present time. The plan of the farm in 1917 is shown in figure 140. As shown by this map, there are now twelve crop fields averaging 23.4 acres

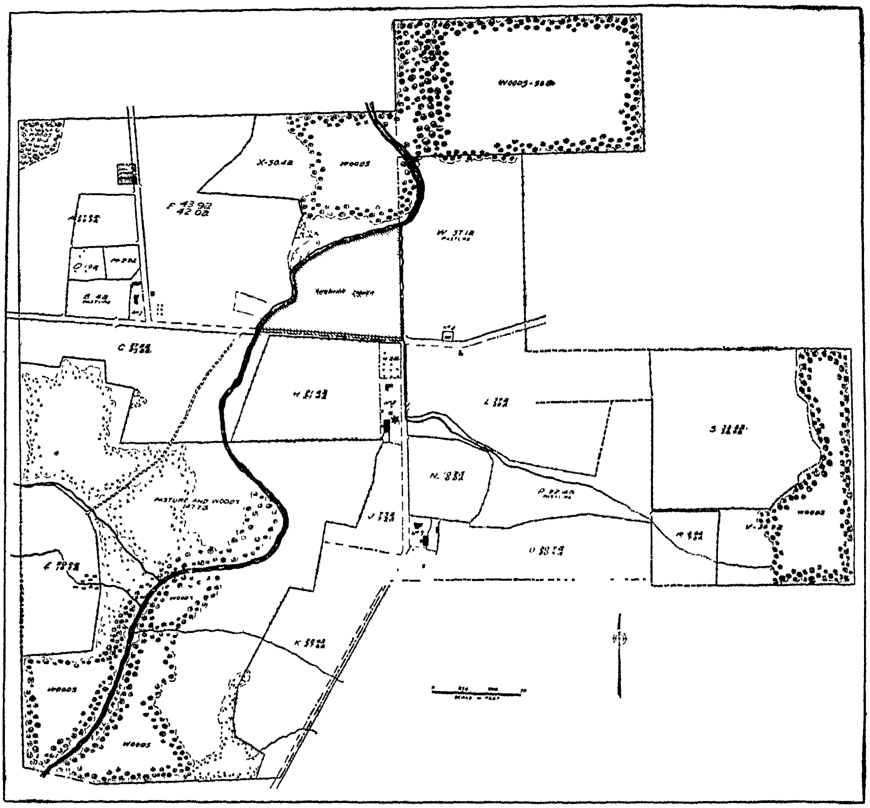


FIG. 140. THE FARM SHOWN IN FIGURE 139, AFTER REARRANGEMENT

The change from sixty-four small crop fields to twelve large crop fields required the removal of less than 300 rods of fence

Farm area, 646.4 acres
Average size of farmed fields, 23.4 acres
Average distance to farmed fields, 117 rods

each, instead of sixty-four fields of 4.3 acres each. These changes have involved little expense and have necessitated the removal of but few fences. Seven fields were combined to form field S, of 38 acres, without taking out a fence. Five fields were combined to form field H, also without removing

a fence. Ten fields have been combined to form fields J and K, and these will later be farmed as one field. Nine fields have been combined to form field F, 42 acres, by taking out 60 rods of barbed wire fence. Six fields have been combined to form field C by taking out 40 rods of barbed wire fence. Seven fields have been combined to form field A, which is farmed in two parts. When opportunity offers, the stone line inclosing 5 acres of this field will be removed and the 26 acres will be farmed as one field. Nine fields have been combined to form field L by clearing an acre of worthless orchard, taking down 30 rods of rail fence, and removing 65 rods of stone fence. This stone fence and the two large stone piles formerly in field T were removed without charge, in return for the providing of a site for a stone crusher which crushed the stone for the construction of a county road thru the farm. The remaining 40 rods of stone and brush fence projecting down into this field will be removed when opportunity offers. Three fields have been combined to form field N, and five to form field O, without any expense. In addition to these changes many trees have been removed from the crop fields for firewood.

The present plan of this farm is not an ideal layout. Many of the fields are irregular in shape and must always remain so because of topography. The shape of a 40-acre field is far less important, however, than the shape of a 4-acre field. There are some short rows in field F, but most of the rows in the field will be from 70 to 100 rods long. The changes thus far brought about have been made at small expense and have been paid for by the saving of labor made possible by larger fields. The owner has been heavily in debt and has not allowed work on improvements to interfere with more important work on crops. His most important job just now is paying for his farm, and nothing should be allowed to interfere with this.

The present arrangement of this farm can be improved materially in the future, when the owner's finances warrant the necessary outlay. The shape of fields F and C can be improved by reclaiming some of the adjoining pasture land. This will necessitate drainage and the clearing off of some stone. Fields J and K can be enlarged and improved in shape by adding some of the pasture land toward the creek. By tiling some of this pasture, it can be made the best crop land on the farm. Fields N and O will be combined by reclaiming some of the pasture P. Field L can never be made regular in shape because of natural conditions, but it may be improved somewhat by extending it toward field S and taking

in part of field P. Field E may be improved and enlarged by drainage, or it may be turned back into pasture. It is rather distant and is not especially good land. The corner of woods in field A will probably be cleared off and this area added to the crop land. The pastures also could be improved by the cutting of some timber. There is, however, plenty of pasture for the stock now kept, and this change would be one of the last to be made.

This farm is larger in area than most farms, but the same principles could have been worked out on a smaller scale on any one of the three farms of which it is composed. It illustrates very well what great improvements can frequently be made at slight expense, by good management.

The second farm

The original plan of the various parcels of land which have been combined into one central New York farm is shown in figure 141. The present area of the farm is 478 acres, and the land was purchased in nine different parcels from as many owners. Some of the persons from whom the present owner bought had already begun the work of combination, so that this farm represents fifteen different farms or parts of farms to the knowledge of the former owners. Except for parcels A and B, the topography of these farms is practically level. There are no physical reasons for the small, irregular fields. The principal crops grown are corn, oats, wheat, and hay.

Considering its topography, parcel B had a fairly good layout, the irregular boundaries of the fields being due largely to this factor. The crop land north of the pasture field 11 was divided into five fields for a five-years rotation. Fields 6 and 10 were cropped but should have been pastured. Both fields are extremely steep. Little stock was kept on this farm, the only field pastured being 11.

Parcel C was a level tract of 100 acres divided into twenty-four small, irregular fields. Except for the road and the woods, the whole farm might have been worked in one field, there being no physical obstacles to this. Fields 9 and 12 were the first fields cleared, evidently because they had drier, warmer soils than the remainder of the farm. They happened to be laid out diagonally to the farm boundaries, and this accident apparently determined the layout of the whole farm. For many years the farm was worked in these small, irregular fields, because it was easier in any one

year to do this than to remove the obstructions. Little stock was kept, and this was pastured on the best tillable land on the farm. The little manure produced was spread on the fields near the buildings. Fields 20,

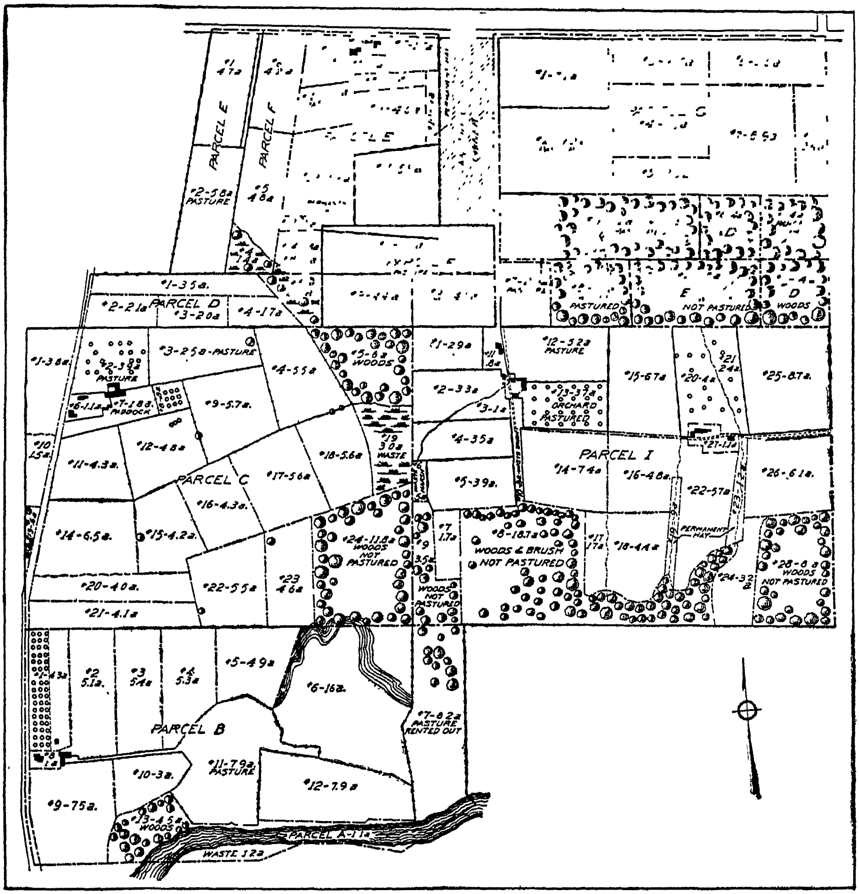


FIG. 141. PLAN OF FIFTEEN FARMS AND PARTS OF FARMS WHICH HAVE BEEN COMBINED INTO ONE FARM OF 477.8 ACRES

The crop land of these farms was divided into sixty-nine small, irregular fields, averaging 4.2 acres each. Except for a part of parcel B the land [illegible]ly level

21, 22, 23, 14, 15, and 18 had not been manured for at least eleven years. Fields 20 and 21 were formerly farmed as one field, as also were fields 22 and 23. Being divided one year by accident, they were farmed afterward

as separate fields. There were few fences, and the whole farm could have been rearranged with little trouble and expense.

Most of the land in parcels D, E, F, and H had originally been included in one farm, with the buildings as shown in parcel E. When the owner of this farm died without leaving a will, the land was divided by the court among the eight heirs, giving each a little piece of crop land and a little piece of woods. This division destroyed the value of the land for farming because each tract was too small. Some of the tracts had already been combined when purchased by the present owner.

Parcel G, a tract of 50 acres, was part of a larger farm. Parcel I had originally been two farms, with building centers as shown. This farm, which is practically level except in the southern part, was divided into twenty-eight small fields. There were several crooked hedgerows which caused irregular fields and wasted much land. Two small open ditches also helped to make the fields irregular.

In all there were one hundred and six fields in the land now occupied by this farm. Little stock was kept and there were few good fences. Some land was cropped which was good only for pasture, and some of the best tillable land was pastured. The woodlots occupied level tillable land except in the southern part of farm I, but contained little good timber. The crop land was divided into sixty-nine small, irregular fields, averaging 4.2 acres each.

In 1907 the present owner of this farm bought parcel B, subject to lease. Possession was not secured, therefore, until 1908. In the next two years a few changes were made in the arrangement of this farm. Fields 6 and 10, which were too steep to be farmed economically, were fenced and pastured. The brush in the pasture field 11 was cut, and some tile was laid in field 12. In 1910 parcel C was purchased, and this step entirely changed the plans of rearrangement. Before the rearrangement of these farms had progressed far, parcel I was bought, in 1912. The remainder of the present farm was purchased in 1914 and 1915.

The results of the work of ten years on the development of this farm layout are shown in the farm plan for 1918, figure 142. Instead of sixty-nine small, irregular crop fields, there are now five main crop fields averaging about 50 acres each, convenient to the buildings. To plow the sixty-nine crop fields of the old arrangement with a 14-inch plow would require about 20,000 turns at the ends of the field, while to plow the five

50-acre fields requires but 6000 turns. More important than the saving in turning by the farming of large fields is the gain in efficiency result-

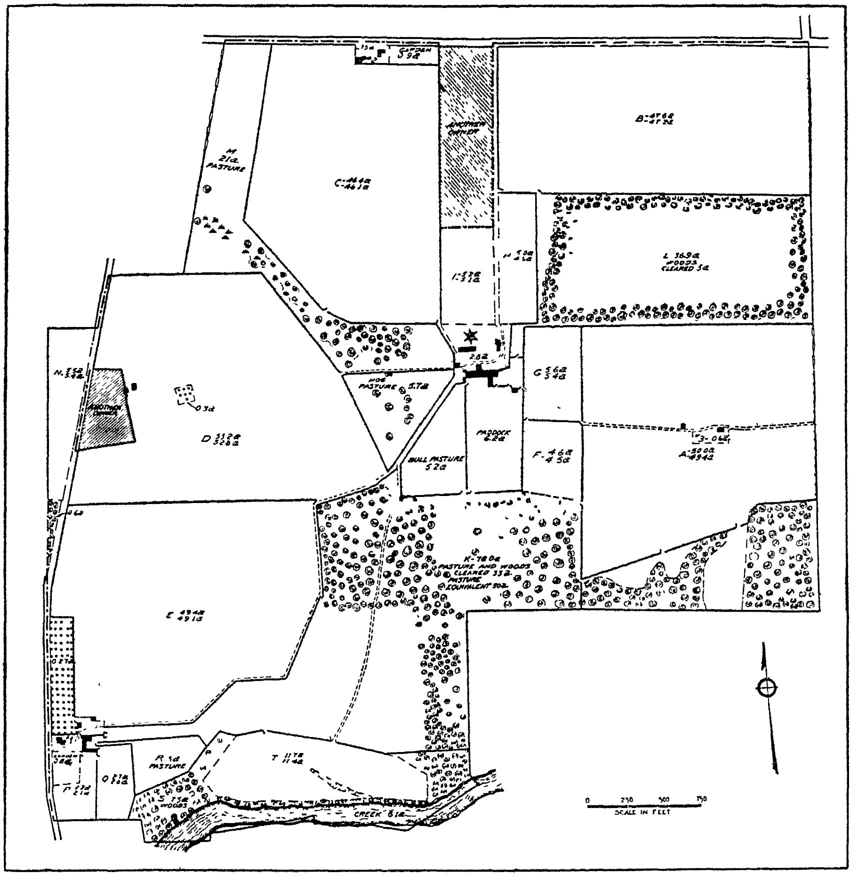


FIG. 142. THE FARM SHOWN IN FIGURE 141, AFTER REARRANGEMENT

Instead of sixty-nine small, irregular crop fields, there are now five main crop fields averaging 50 acres each, convenient to the buildings. The average distance to the farmed fields is 60 rods

Farm area, 477.8 acres
Average size of farmed fields, 28 5 acres
Average distance to farmed fields, 60 rods

ing from the driving of more horses to each man and the use of larger machines. Dragging is done with four horses instead of two. A four-horse drill has replaced the two-horse drills and a four-horse binder is

used. Larger fields permit the effective use of larger machines and more horses to the team, and thus greatly increase the efficiency of labor.

The present layout provides for a better utilization of land. About 6 acres have been added to the crop land by eliminating hedgerows and useless fences. The entire farm is now fenced but the fences occupy only 2.8 acres. About an acre was added to the crop land by tiling open ditches, while a much greater area which had previously been in permanent hay was thus made tillable. About 26 acres which had previously been lying idle in brush or swamp were made productive by including them in the pastures. In addition to this, 45 acres of woodland were added to the pasture area. Thirty-six acres of land which was too steep or too wet to be cultivated, but which had formerly been in crops, were added to the pasture land. In addition, 8 acres of poorer crop land were utilized in paddocks near the buildings. Fifty-two acres of the best land on the farm, which had formerly been pastured, were added to the crop land.

The arrangement of pastures in this layout is very convenient. Each of the main crop fields can be connected with a permanent pasture, and hence with water when temporarily pastured. The paddock of 6 acres south of the main farmstead forms a wide lane to the main pasture. There will certainly be no waste land in this lane. The small pastures for the bull and the hogs save much time. The other pastures are likewise so arranged as to open up near the buildings.

The four small crop fields, F, G, H, and I, are used for a rotation of beets, potatoes, and other minor crops. Field T has been kept in alfalfa most of the time. Field N is too distant to be worked to advantage and will probably be disposed of. It adjoins a larger field of another farm, shutting this field off from the highway. Fields P, Q, and R are used for stock kept at the adjacent farmstead. The houses designated as No. 2 and No. 3 are used as tenant houses for hired men.

Along with the fields, the buildings of these farms have likewise been rearranged to adapt them to present conditions. The main farmstead has been developed at the center of the farm convenient to the fields. A house and a few barns were already located here. By using these barns and the frames and lumber from the other barns scattered over the original farms, a well-planned centralized set of buildings has been developed. They have adequate storage capacity and are conveniently arranged for work.

Further changes will be made in the future. The woods will be cut from field L, and the land will be pastured until the stumps rot and will finally be added to the crop area. The southern part of field A is rather poor. When the present fence gives out, a new fence will probably be put thru from the east end, parallel to the farm boundary, thus adding a few acres to the pasture. To replace the area lost, fields F and G may be added to field A. One of the more distant tenant houses will probably be moved to a location near the main farmstead. This will save much useless walking.

The changes in this farm have been made more rapidly than would ordinarily be justified, but they have not interfered with the successful operation of the farm. The original small fields have been gradually combined into larger units without seriously interfering with crop production.

REARRANGEMENT OF A NORTHERN NEW YORK FARM

The plan of a northern New York farm as existing in 1912 is shown in figure 143. This farm was rather long and narrow, with the buildings at

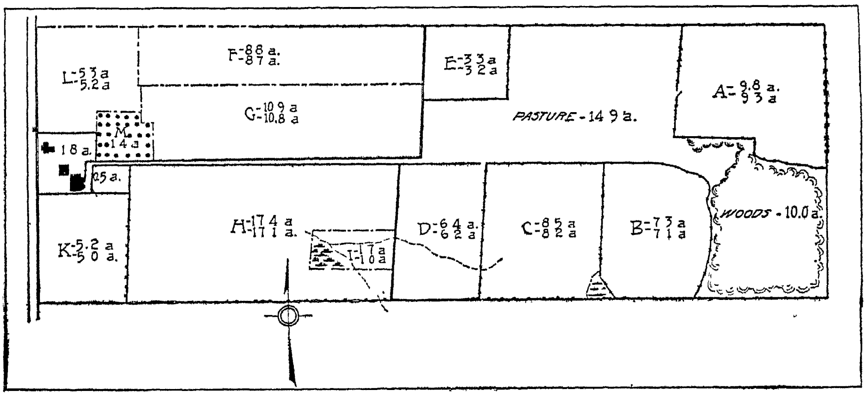


FIG. 143. PLAN OF A NORTHERN NEW YORK FARM IN 1912

Farm area, 116 acres
Average size of farmed fields, 7.4 acres
Average distance to farmed fields, 74 rods

one end. There were eleven farmed fields averaging 7.4 acres each, the average distance to the nearest corners of the fields being 74 rods.

The owner of the farm wanted more land, and in 1913 he purchased the 118-acre farm directly across the road, making a total farm area of 234

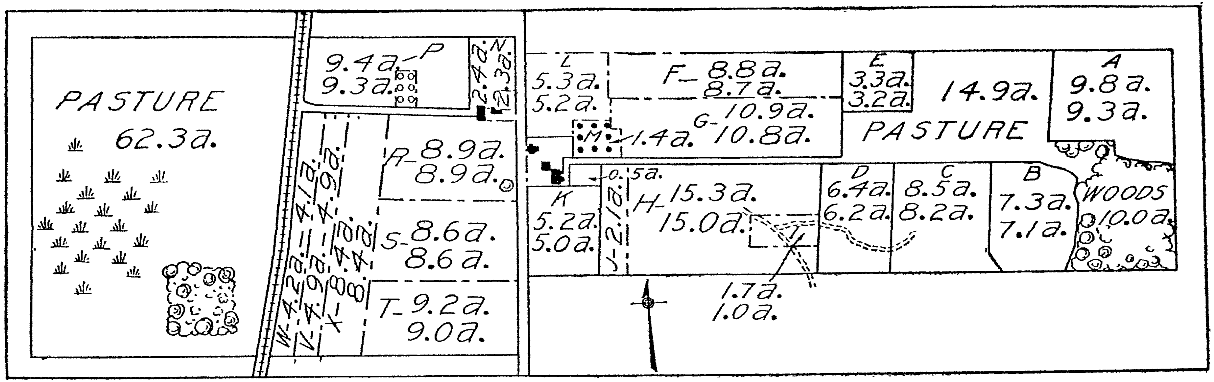


FIG. 144. THE FARM PLAN SHOWN IN FIGURE 143, IN 1913

In 1913 the 118-acre farm across the road was purchased, making the total farm area 234 acres. In this case the buildings were brought into the middle of the farm by buying the land across the road

Farm area, 235.3 acres
Average size of farmed fields, 7.1 acres
Average distance to farmed fields, 64 rods

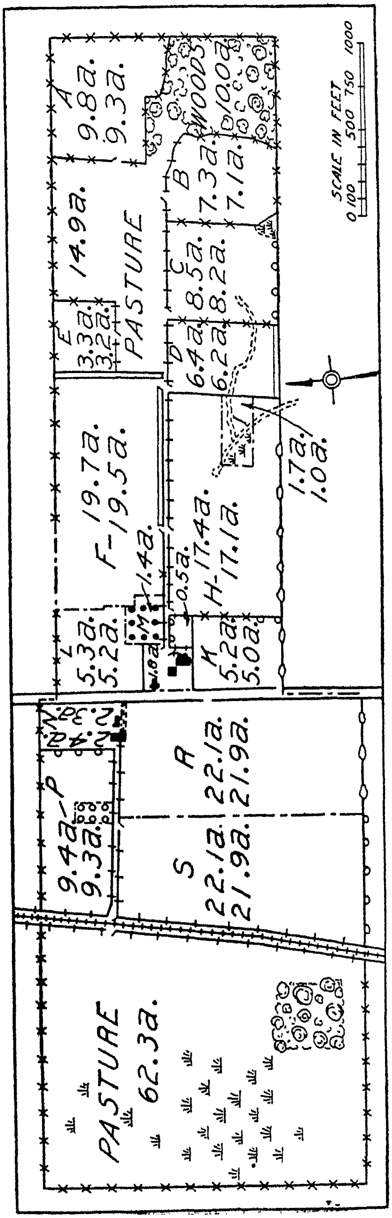


FIG. 145. THE SAME FARM IN 1917

Since 1913 the layout has been further improved by enlarging and combining some of the crop fields

Farm area, 235.3 acres
Average size of farmed fields, 10.5 acres

acres. The crop land of the new farm was more convenient for farming than the land on the original farm. Altho the farm was doubled in size by the purchase, the average distance traveled to fields was actually decreased from 74 rods to 64 rods. The plan of the two farms is shown in figure 144.

By this combination two small farms, either one of which was too small to furnish a satisfactory living with the type of farming made necessary by soil and other conditions, were combined into one farm large enough to be operated successfully and economically. The large area of pasture on the newly purchased farm was needed for keeping a good-sized herd of cows. It was easily reached by the lane and a cattle-pass under the railroad. The other house was used for a hired man, and the other barn for young stock.

Since 1913 many of the fields have been combined and enlarged. The plan of the farm as it existed in 1917 is shown in figure 145. There are four main fields — F, H, R, and S — of good size and shape, and several smaller fields. The small fields A, B, C, D, and E are pastured in rotation. The soil is very sandy and does not hold grass well. The changes that have been made in the field arrangement did not require the moving of a single fence. All that was needed was a little care and thought in planning crops so that the fields could be combined. There is still opportunity for further improvement in the layout.

This plan shows one example of locating the buildings in the middle of the farm by buying the land across the road. Not only was the layout improved by this means, but one successful farm was made of two unprofitable ones.

REARRANGEMENT OF A WESTERN NEW YORK FARM

The plan of a western New York farm as it existed in 1910 is shown in figure 146. The farm is located in a general farming region where little stock is kept. Two cows were kept on the farm for home use. There was no other stock except horses. Apples, peaches, potatoes, cabbage, and wheat are grown for sale in this section, also corn, hay, and some oats for farm use. The topography is gently rolling and nearly all of the land is tillable. The soil varies in different parts of the farm, but in general it is a fine sandy loam.

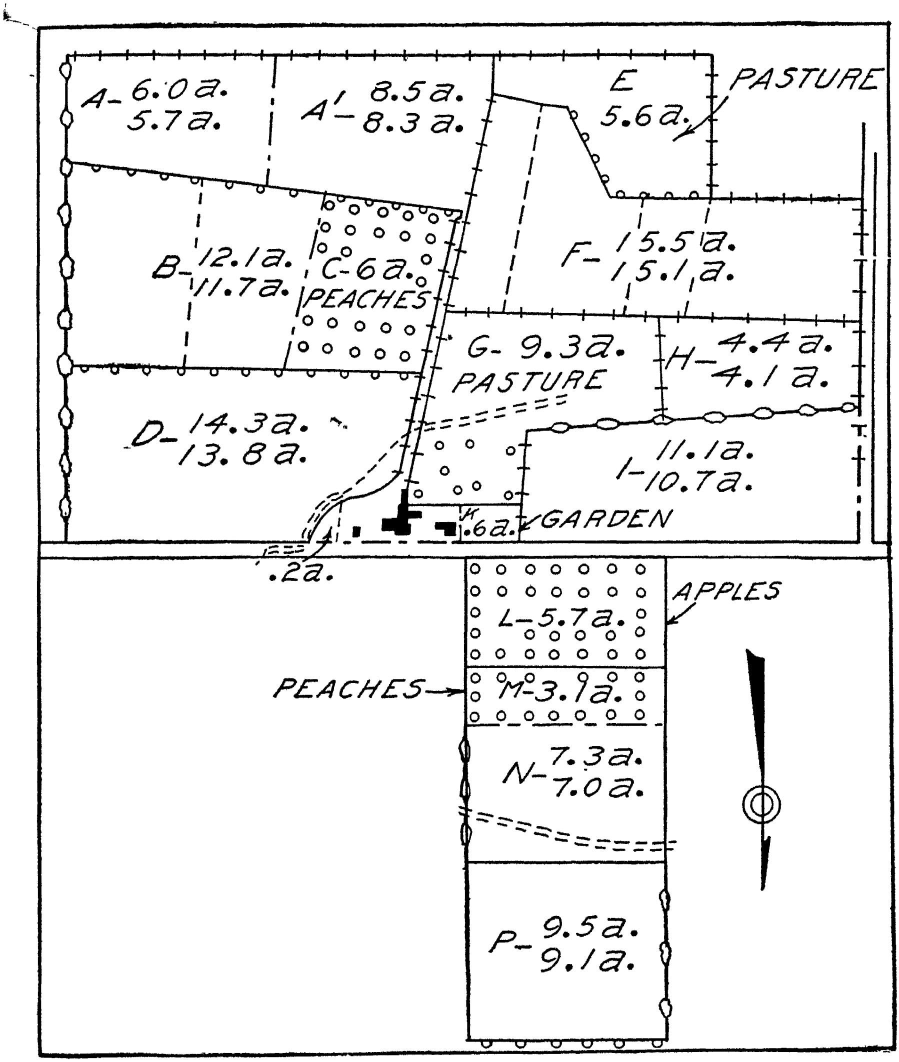


Fig. 146. rearrangement of a western new york farm — I

Plan in 1910, before rearrangement

Γhis plan illustrates the chance way in which most farm arrangements ve developed. Field E happened to be a wet piece of land and was refore put into pasture. This made a lane necessary. The lane was ı directly from the barn to the pasture, diagonal to the farm lines. peach orchard was planted along the lane, with rows parallel to it, thus ing its location permanently. Every field on the farm was irregular shape, with a greater or less number of short rows. Even fields of rly good size which could have been farmed in one piece were farmed in all patches; field F, for example, in 1912 was divided into four patches, corn, potatoes, cabbage, and beans, respectively, with the rows running ›sswise, as the field lines indicate. The fence lines were full of stone and ısh and wasted much land. The brush and stone fence between fields and I occupied a strip of land about 24 feet wide. The rail and stone ıce between fields A and B occupied a strip of land 14 feet wide.

The farm was purchased by the present owner in the fall of 1912 and he gan clearing up at once. After a careful study of conditions he planned earrangement, and began to work out his plan gradually, as opportunity rmitted. In 1912, 40 rods of the old rail and stone fence between lds A and B was removed. In 1913, 2.5 acres of the pasture F (fig. 147) ıs added to the crop land of field H, a woven wire fence was built inclosing ld F, and the old rail pasture fence was removed from field H. Also, woven wire fence was built between the wet pasture I and the old chard M. In 1913 and 1914, the two cross fences were cleared out of ld K, which appears as the first field of the new layout, a rectangular ld of 13.8 acres. About 100 loads of stone from these fences were drawn the barnyard. In 1914 an old stone line was removed from field S. ıis permitted fields R and S to be farmed in two fields, instead of three theretofore. Other minor changes made in 1914 were the removal of e road fence of field K, the completion of the lane fence, and the removal the stone and brush fence between fields J and L. Field G was put in ïalfa to save farming the short rows caused by the lane along the side.

The plan of the farm in 1915, now beginning to take shape, is shown in ;ure 148. In the spring of 1915, the rail fence north of field C, running ross fields A and C, was removed. Apple trees were set out in field I. The nce between fields E and H was cleared away, as well as the fence south field C. There were 30 loads of stone in these fences. A start was made so in removing the stone wall south of field L. Perhaps the most impor- nt work done in that year was the rearrangement of the farm buildings.

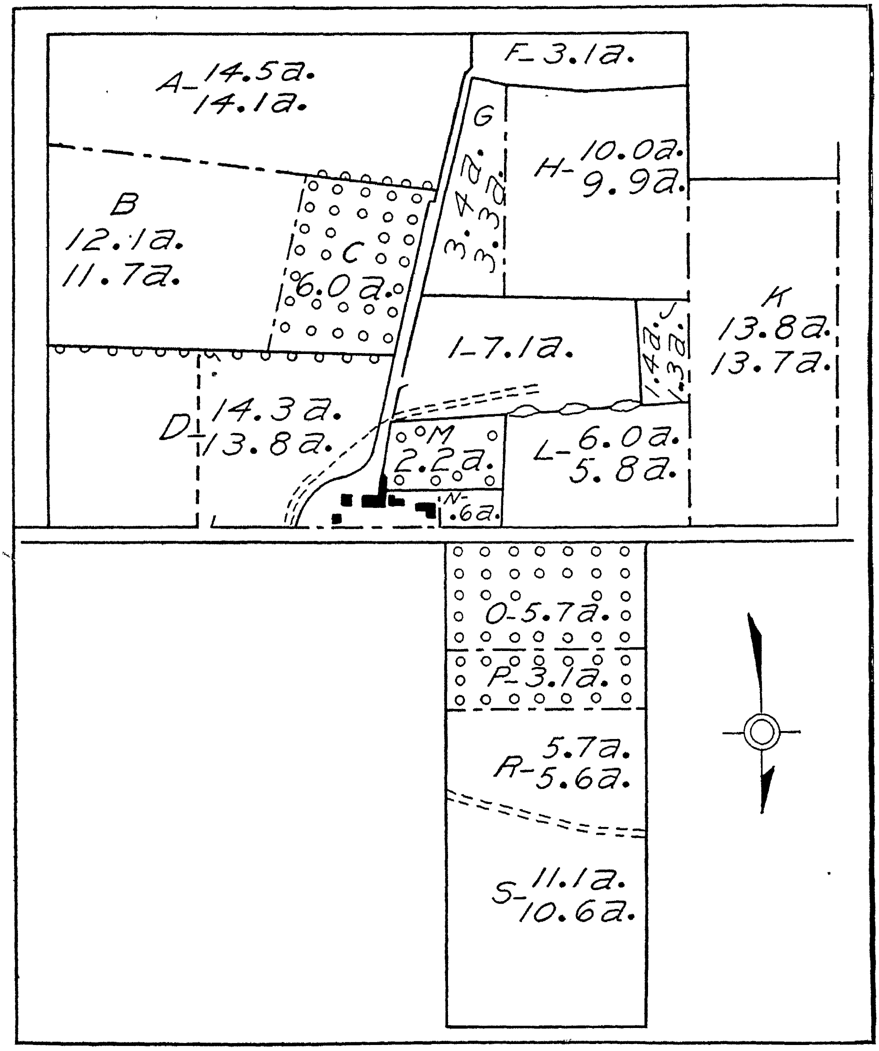


FIG. 147. REARRANGEMENT OF A WESTERN NEW YORK FARM — II

Farm plan in 1914. Some old fences have been removed and field K appears as the first field of the rearrangement

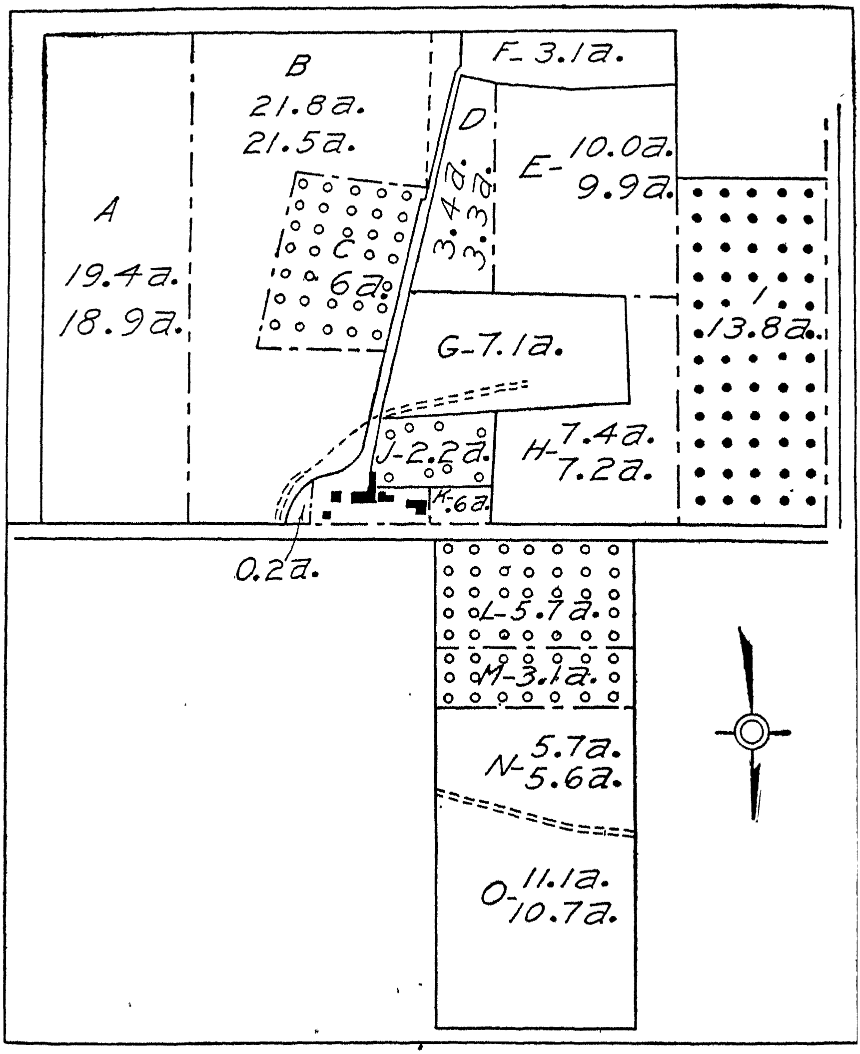


FIG. 148. REARRANGEMENT OF A WESTERN NEW YORK FARM — III

Farm plan in 1915. More fences have been removed and fields A and B begin to take shape. The farm buildings were rearranged in 1915

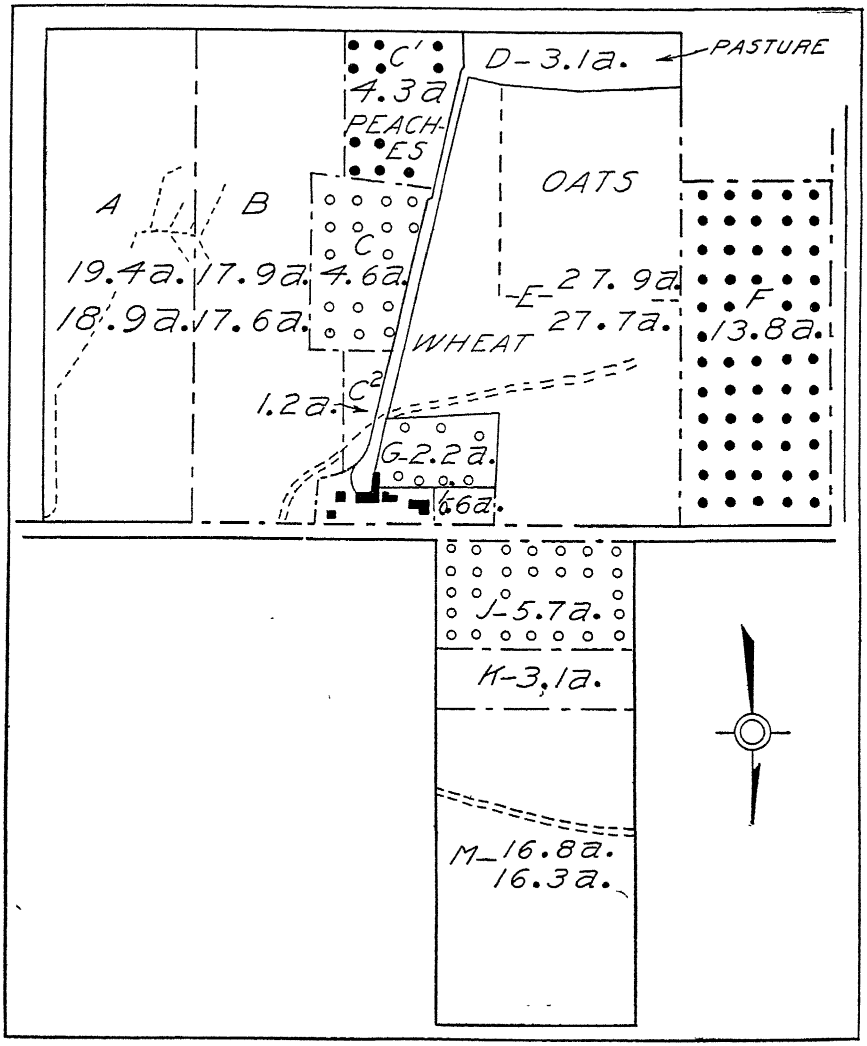


FIG. 149. REARRANGEMENT OF A WESTERN NEW YORK FARM — IV

Farm plan in 1918

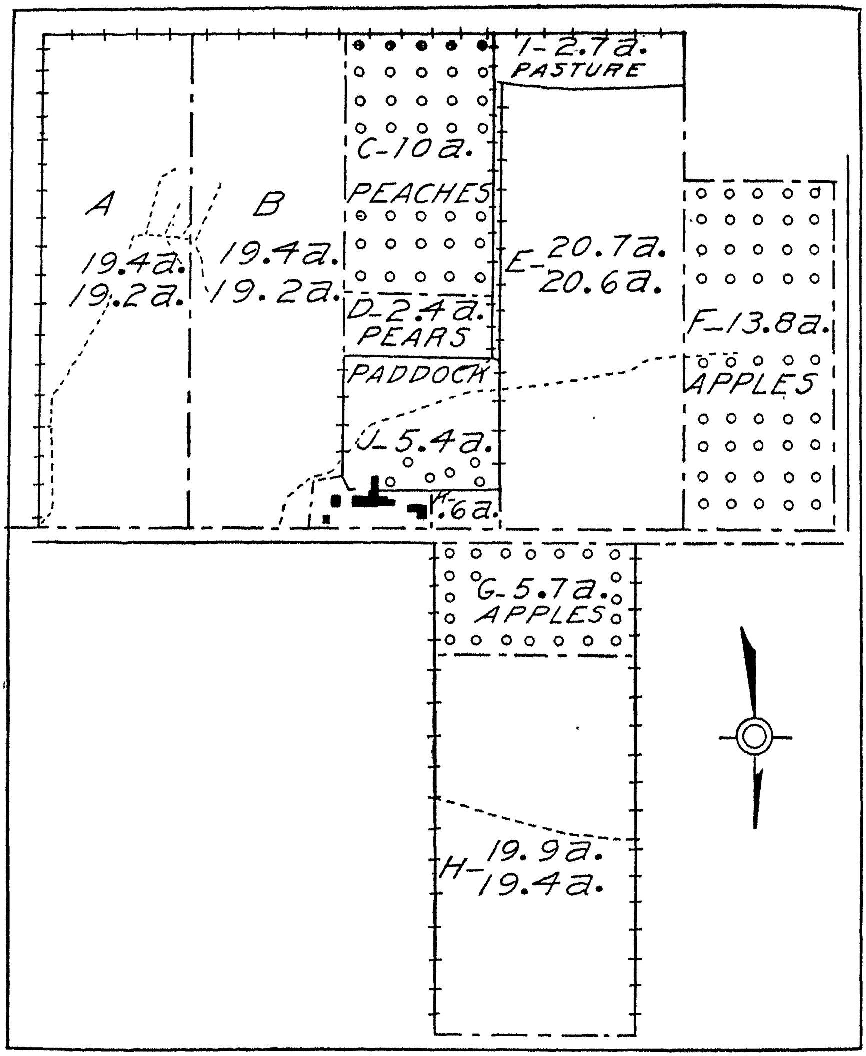


FIG. 150. REARRANGEMENT OF A WESTERN NEW YORK FARM—V. FINAL PLAN

Instead of small, irregular fields, as in the original plan, there will be four large rectangular fields of about 20 acres each and averaging nearly 100 rods long. About 10 acres of crop land has been gained. Much more important than this, however, is the saving of labor made possible by improving the size and shape of the fields

Farm area, 125.4 acres

The next step in the development of this rearrangement, the farm plan in 1918, is shown in figure 149. The remainder of the stone wall south of field J was drawn to the barnyard in the spring of 1916. There were about 150 loads of stone. The stone fence along the north end of field B, about 50 loads of stone, was cleared away during 1916 and 1917. Twenty rods of the stone fence north of field E was cleared away in 1917, and the line fence along fields E and F was removed. The old 7-acre pasture south of the old orchard G was cleared, and was sowed to wheat with the remainder of field E in the fall of 1917. Thirty-five loads of stone were removed from the fence along the north side of this pasture. A line of tile with some laterals was laid in field A to drain the low area in the middle of this field. In the spring of 1918, 4.3 acres of peach trees were set out in field C^1 to fill up the short rows south of the old peach orchard C. Since the trees on the east side of this orchard were deteriorating, 1.4 acres of them were pulled and the area cleared was added to field B. The peach trees in field K had become worthless. This field was pastured in 1918 and the trees were pulled in the late fall.

The owner's final plan for the rearrangement of his farm is shown in figure 150. The general crop land will be divided into four rectangular fields of about 20 acres each. Two of these fields are 100 rods long, and field H, which is the shortest, is 80 rods long. In addition to the general crops there will be about 20 acres of apples, 10 acres of peaches, and 2.4 acres of pears. The former diagonal lane will be replaced by the lane shown, running from the corner of the paddock J. The open ditches thru fields H and E will be tiled. Finally, the owner plans to clear up the stone and brush in the line fences with the help of his neighbors. These fences will then be replaced by woven wire or the areas will be left unfenced, as circumstances determine.

Probably about ten years will be required to rearrange this farm layout. The work done thus far has been performed at odd times and has not interfered with the successful operation of the farm. The owner is making an excellent living from the farm, is enjoying life, and at the same time is constantly making his farm more valuable. If possible he will rent or buy about 20 additional acres of land for general crops, so that a five-years rotation can be followed.

The contrast between the original and the ultimate layout of this farm shows plainly the advantages of the rearrangement. Instead of nine fields farmed in fourteen irregular patches of an average size of 6.2 acres

each, there will be four rectangular crop fields averaging 19.6 acres each. About 10 acres of crop land has been gained, 3 acres by clearing fence rows and 7 acres from pasture. Crop land is worth $125 an acre. More important than the land gained, however, is the saving in labor made possible by improving the size and shape of the fields.

POSSIBLE REARRANGEMENTS OF SOME NEW YORK FARMS

While comprehensive rearrangements such as the preceding have been worked out on comparatively few farms, a growing number of farmers are beginning to plan some improvements of their farm layouts. In making such improvements it is important to have a fairly definite scheme of rearrangement in mind. As time goes on and the work proceeds, the details of the plan will probably be changed many times. Much thought, much time, and a great deal of work are required for the satisfactory execution of such a plan, but the results should be worth while.

In the following pages a few examples are given of possible rearrangements of farms. Considering all farm conditions an attempt has been made to plan a satisfactory layout for each. The rearrangements suggested are not the only ones possible, and probably are not the best possible, but they offer an improvement over present conditions.

POSSIBLE REARRANGEMENT OF TWO CENTRAL NEW YORK FARMS

The first farm

The plan of a central New York farm of 126 acres is shown in figure **151**. Most of the land is tillable and in crops. The topography is rolling, but not steep enough to interfere with the use of machinery. The principal crops grown are silage corn, corn for grain, potatoes, oats, wheat, hay, apples, and alfalfa. Potatoes, wheat, apples, milk, and some hay are sold. A small herd of from eight to ten cows is kept. The soil is light enough to be worked easily, but grows good grain and hay. In general, a four-years rotation, of corn and potatoes, oats, wheat, hay, is followed. Occasionally the hay is left down for more than one year.

The present layout of this farm as shown on the map is much better than that of most farms. The fields are of fair size, most of them are regular in shape, and they are convenient to the buildings. The farm is made up of three parts, fields H and I from one farm, and field J from another, having been added to the original farm by the present owner.

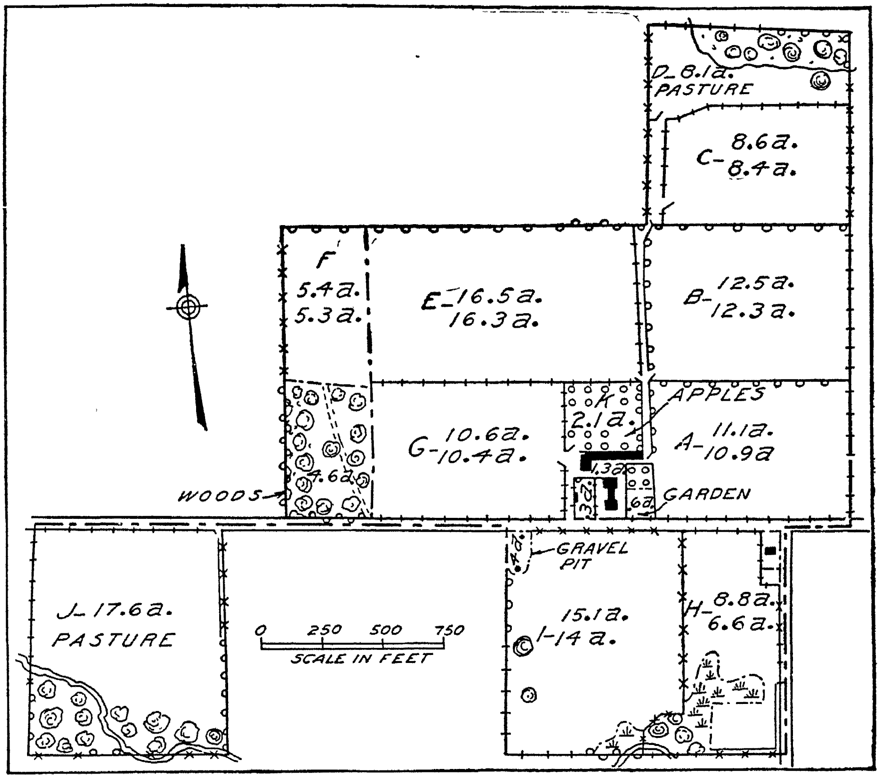


FIG. 151. PLAN OF A CENTRAL NEW YORK FARM IN 1915

Farm area, 126.3 acres
Average size of farmed fields, 10.5 acres
Average distance to farmed fields, 32 rods

Since there are eight fields and a four-years rotation is followed, the fields have been farmed in pairs, as follows: A and C, B and G, E and F, and H and I. Field H has been pastured a part of the time because of the swampy

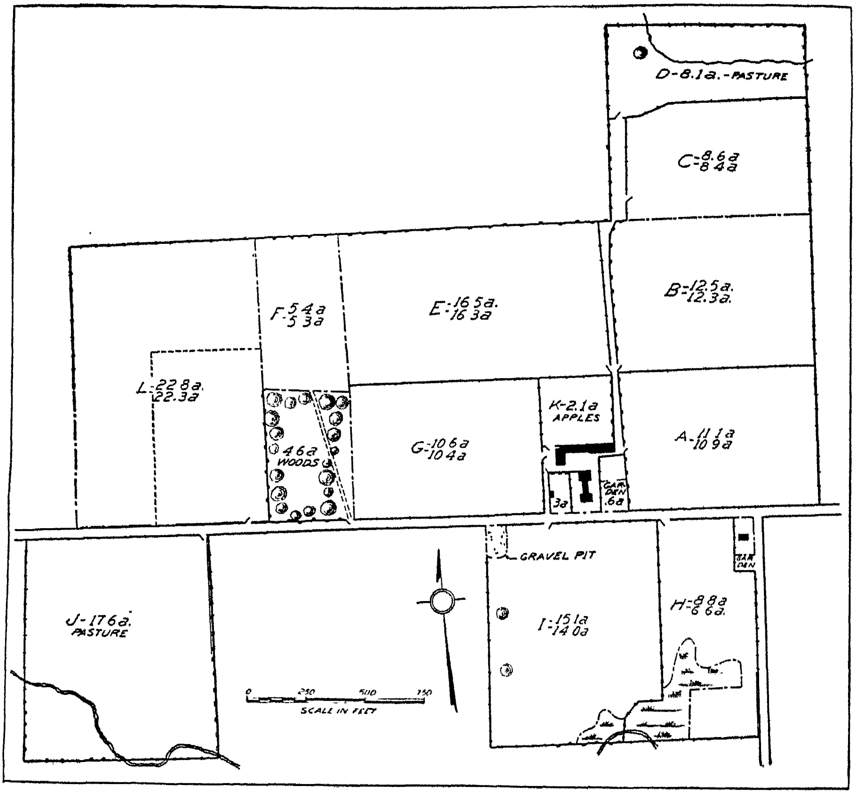


FIG. 152. PLAN IN 1917 OF FARM SHOWN IN FIGURE 151

The land appearing as field L on this plan formerly belonged to a farmer who lived three-quarters of a mile away. In the spring of 1917 it was added to this farm

Farm area, 149.4 acres
Average size of farmed fields, 10.6 acres

spot in the lower side, which cannot be easily drained. The cows are driven down the highway to the pasture J, a distance of about 100 rods.

More land was needed, and, having a good opportunity, the owner purchased a tract of about 24 acres on the west side of his former holding, in the spring of 1917 (fig. 152). This land belonged to a farmer

who lived three-quarters of a mile away, and had been worked under this disadvantage for many years. Being located far from the buildings, this land had received no manure and but little care. The land was run down and the fence rows were full of brush and stones. It was evidently

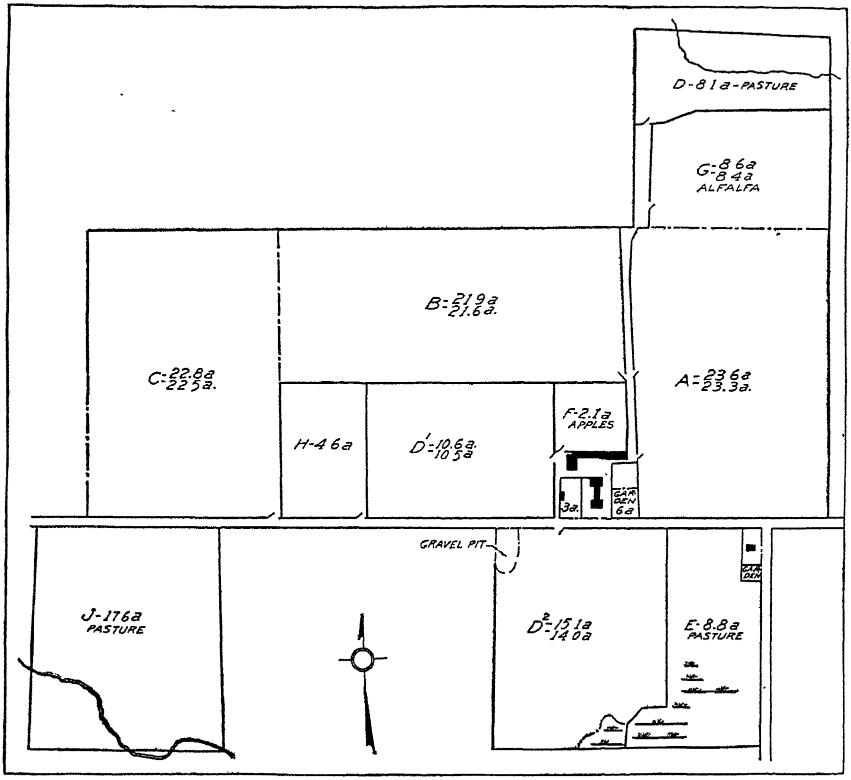


FIG. 153. A POSSIBLE REARRANGEMENT OF THE FARM SHOWN IN FIGURE 152

Few changes would be required to enlarge and combine the fields as suggested
Farm area, 149 4 acres
Average size of farmed fields, 16.7 acres
Average distance to farmed fields, 38 rods

worth much more as a part of an adjoining farm than as a part of a farm nearly a mile away, and the change in ownership finally took place.

A good plan of rearrangement for the present farm is shown in figure 153. The necessary changes are relatively few and could be made in a few years. Fields A and B of the present plan would be combined to make the new

field A. This would involve only the removal of the woven wire fence between the two fields. The present field C is labeled G in the new plan and would be kept in alfalfa. The present fields E and F would become the new field B. The new field C is the land last purchased. An unnecessary rail fence between the new fields B and C has already been removed. The lower part of the west boundary of the new field C was formed by a brush and stone fence row which wasted a strip of land more than a rod wide. The brush ranged in size from small brush to trees 8 inches in diameter, and there were about 20 loads of stone. To clear up and plow this 36 rods of hedgerow required about 90 hours of man labor and 45 hours of horse labor. At 25 cents an hour for man labor and 40 cents for a team, the cost of this work would be $31.50, or 87½ cents a rod. A quarter of an acre of land was reclaimed, worth from $20 to $25, and thus the net cost of removing the obstruction was low.

Fields D^1 and D^2 would be farmed together to make the fourth field of the new layout. The present 4.6-acre woodlot occupies level tillable land which would be worth $100 an acre if cleared. It contains practically no timber but the trees are being cut for firewood for home use and for sale. It is planned to cut off all the wood in about five years, approximately a fifth having been cut during the winter of 1917-18. After the timber is cut, this stump lot will be cleared for cropping as soon as possible. Since there is no water supply it cannot be conveniently pastured while the stumps are rotting.

The proposed layout has five large fields which are to be farmed as four, averaging 23 acres each, besides one field for alfalfa. Eventually the stump lot H will be cleared and added to the crop area.

The owner of this farm is looking ahead still further. It will probably be possible in a few years to buy the 24-acre field which lies between the present fields I and J. This lot is farmed at great inconvenience by a man who lives a mile away. It is worth much more to the man who lives across the road. If this land is acquired, the rearrangement shown in figure 154 will be made possible. This plan would provide for four fields of about 30 acres each, and 8 acres for alfalfa. The four main crop fields are of fairly good shape and all are convenient for working. Altho field C is nearly square, this is not a serious drawback in a field of 30 acres. The cost of the necessary changes would be small and the saving of labor would pay the entire expense in a few years. Five acres of crop land would

be gained, mostly from the woodlot. The value of this land would more than cover the cost of clearing.

On the east side of this farm is a small farm comprising 30 acres of rather poor land with poor buildings. Since the latter farm is too small to pro-

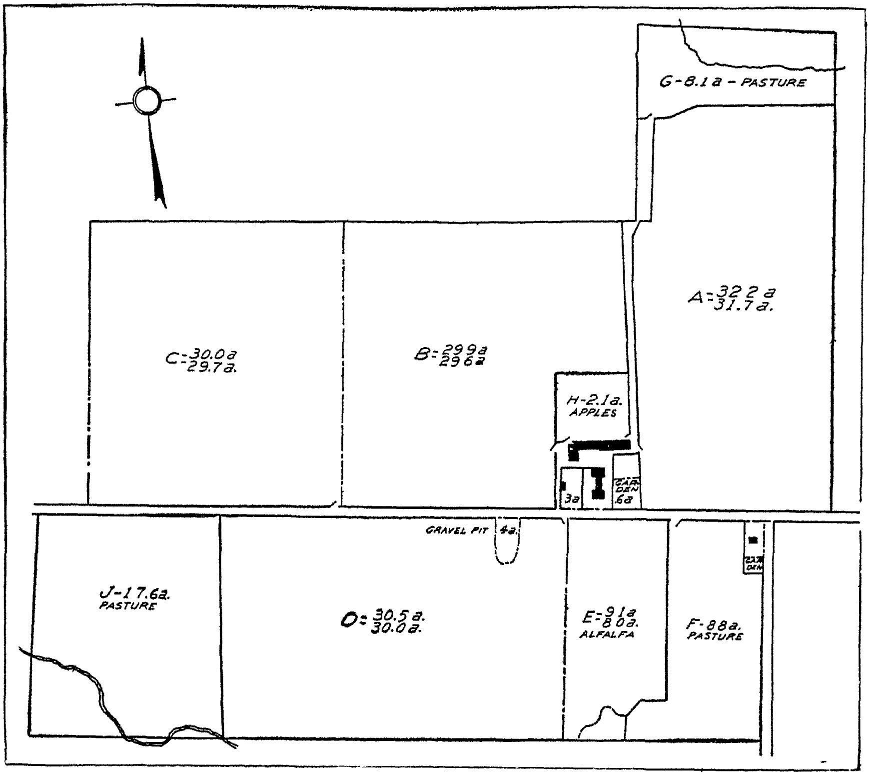


FIG. 154. ANOTHER POSSIBLE REARRANGMENT OF THE FARM SHOWN IN FIGURE 152

The land shown as field D in this plan belongs to a farmer who lives a mile away, and is thus worked at a great disadvantage. The land is worth more to the owner of this farm, and if it were acquired by him the farm might be rearranged as suggested. Four long crop fields are provided for a four-years rotation, and in addition there is a small field for alfalfa

Farm area, 173 4 acres
Average size of [illegible] 25 8 acres
Average distanc [illegible] 30 rods

duce a satisfactory living, it will probably be for sale in a few years. If it can be purchased reasonably, this land will be added to the farm under consideration, for pasture. Since it adjoins the small pasture at the north end of the farm, it would make a valuable addition to the pasture land.

In such a case the pasture J could be used for dry stock and the cows would not have to be driven daily down the road to pasture.

Neither of these suggested rearrangements may ever be entirely realized. Changing conditions may make some other arrangement more desirable or a better plan may become possible. By planning for the future development of his farm, however, this farmer will be ready to take advantage of every opportunity for furthering his plan.

The second farm

The plan of another farm in central New York as it existed in 1915 is shown in figure 155. The soil is very heavy but most of the land is tillable. The topography is rolling. The principal crops grown are silage corn, oats, barley, wheat, hay, and alfalfa. A large dairy herd is kept, the pasture being supplemented by the feeding of silage and alfalfa in summer. This farm is made up of parts of four 50-acre farms, the history of which has already been given (page 398). As shown by the map, the farm was divided into sixteen crop fields, most of these being small in size and irregular in shape. In many of these fields the irregularity in shape was caused by the long open ditch which passed thru part of the farm. The ditch occupied more than an acre of land and necessitated more than two hundred short rows. The 50-acre tract on which the ditch was located was formerly a separate farm, with the farmstead located as shown, near the orchard R. The house was used by the present owner for a tenant house, altho it was very inconveniently located.

More land was needed, and in the spring of 1918 the intervening farm of 54 acres was purchased. This farm had been unprofitable for years because it was too small and was poorly farmed. The land had received no manure and was badly run down. The present layout of the combined farms is shown in figure 156. Some changes have been made in the original farm since 1915. Most of the open ditch has been tiled and the land formerly occupied by the ditch has been cleared for crops. Some of the fields have been enlarged and combined. Some old apple trees have been cleared out of field N. The pasture field B has been plowed and is being temporarily cropped, and the former night pasture, field I on the 1915 plan, has been added to field E.

A possible rearrangement for this farm as now constituted is shown in figure 157. While far from ideal, this plan satisfies the requirements and yet considers the natural features of the farm. A five- or six-years rota-

tion is followed, of silage corn, oats or barley, wheat, hay for two or three years. In addition a considerable area of alfalfa is grown. The

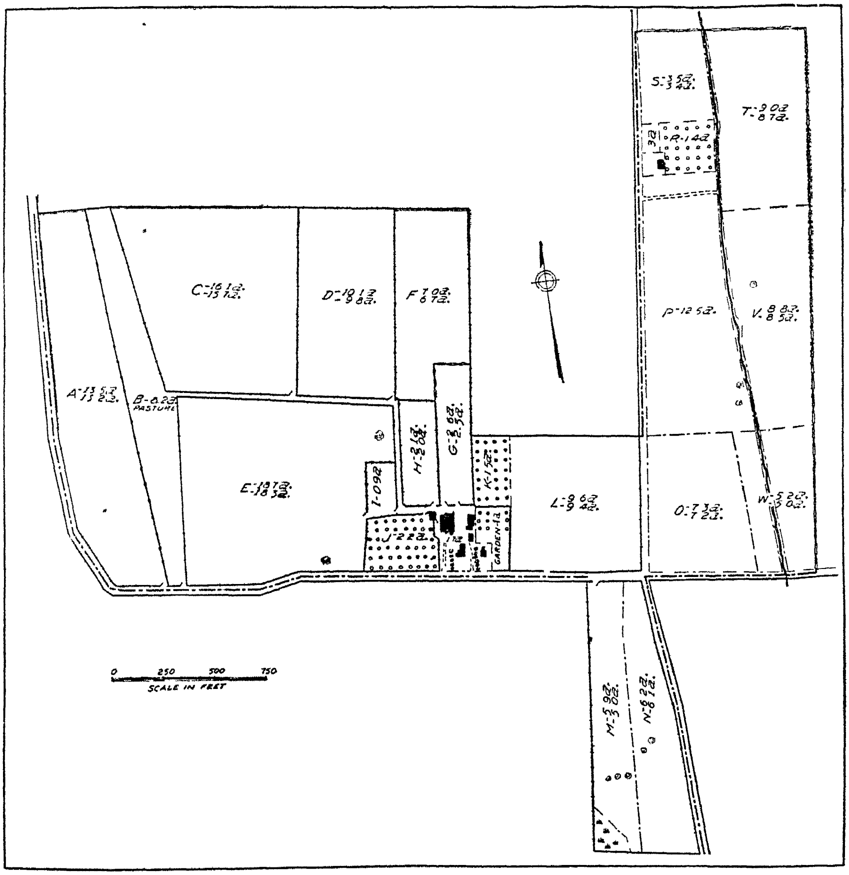


FIG. 155. PLAN OF A CENTRAL NEW YORK FARM IN 1915

As is here shown, this farm was made up of three original 50-acre farms and part of a fourth farm

Farm area, 162 acres
Average size of [illegible] acres
Average distanc[illegible] 80 rods

rearrangement provides for six main crop fields of from 24 to 29 acres each, and several fields for alfalfa. The fields are reasonably convenient to the buildings and are as regular in shape as the shape of the farm will

allow. In this case it is impossible to buy land across the road to put the buildings in the center of the farm.

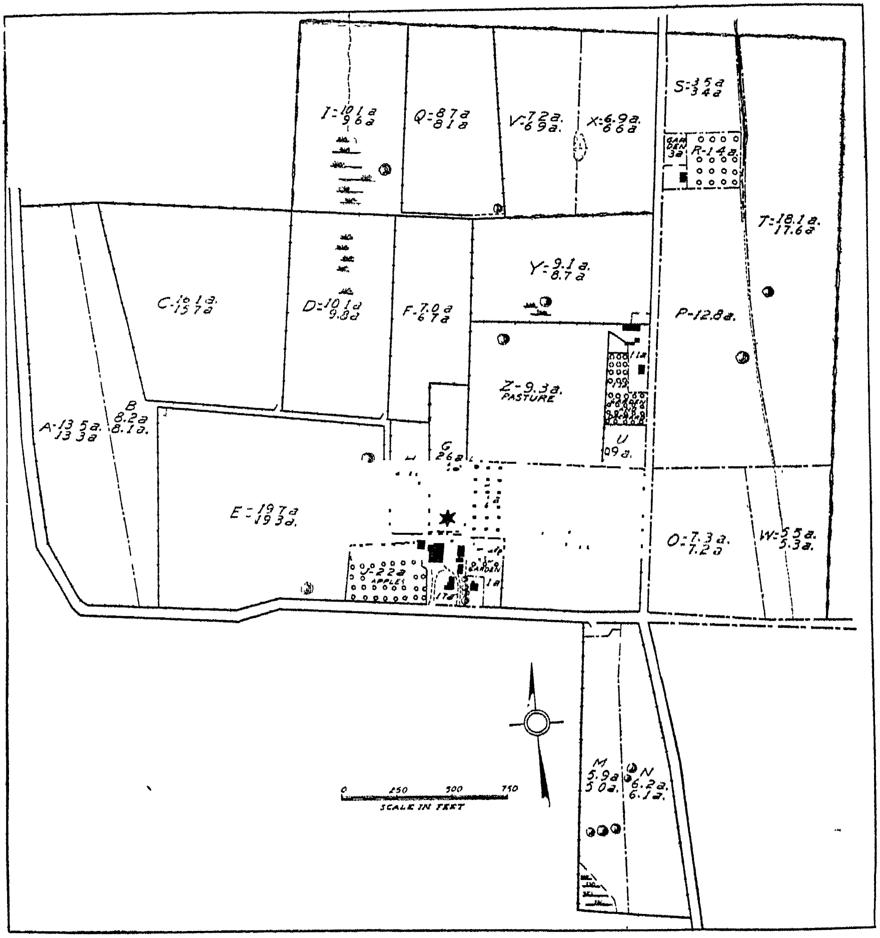


FIG. 156. PLAN IN 1918 OF FARM SHOWN IN FIGURE 155

In the spring of 1918 the intervening farm of 54 acres was added to the farm shown in figure 155, increasing the area to 216 acres. Some improvements in the former layout have already been made, the most important being the tiling of the open ditch between fields P and T

Farm area, 216.5 acres
Average size of farmed fields, 9.2 acres

Field A of the new plan would be made up of two parts farmed together, A being the present field C, and A² being formed from parts of fields V

and X. A would be made square by running the west side out to take in a little of the hill pasture. Field B of the rearrangement would be made

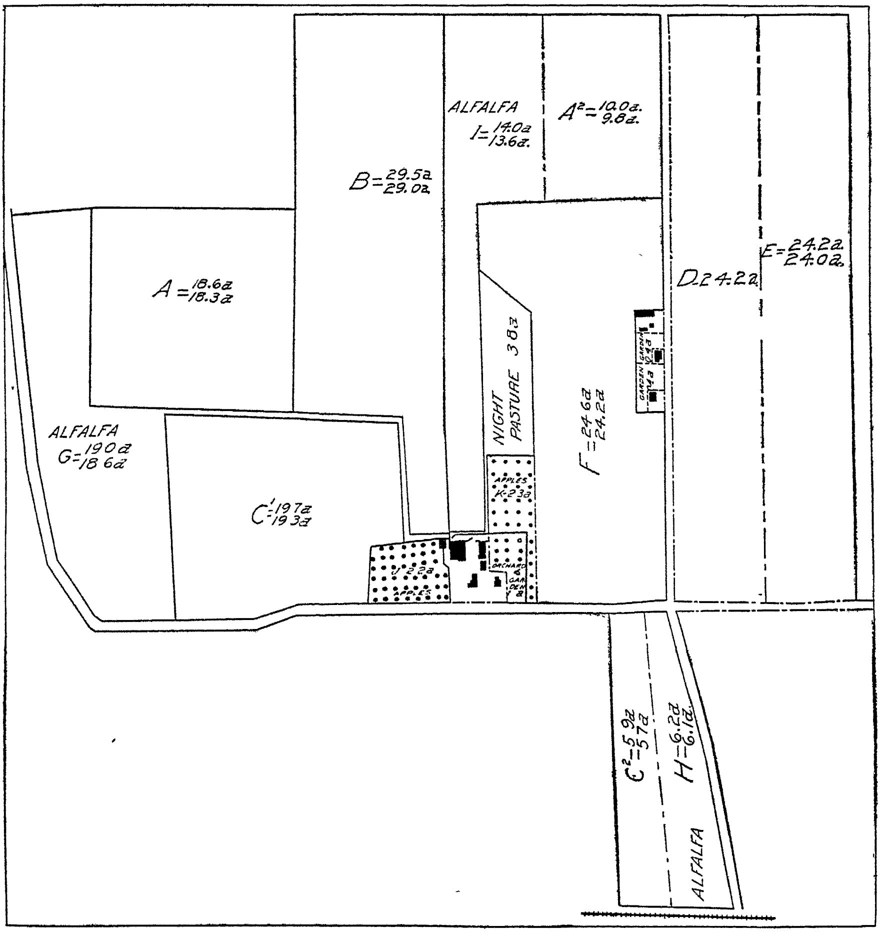


FIG. 157. A POSSIBLE REARRANGEMENT OF THE FARM SHOWN IN FIGURE 156

Five large fields are provided for a five-years rotation, and three fields too rough to be cultivated are left for alfalfa. While far from ideal, this layout represents a great improvement over the former plan and yet meets the peculiar soil and topographical conditions of the farm

Farm area, 216.5 acres
Average size of farmed fields, 19.3 acres

up of the present fields D, H, and I, together with parts of fields F and Q. The new field C, made up of the two parts C^1 and C^2 to be farmed together,

would include the present fields E and M. The new fields D and E would be rectangular fields 160 rods long, made up of the present fields O, P, R, S, T, and W. The new field F would be made up of parts of the present fields U, Y, Z, and L.

Fields D and I of the present plan have been nearly useless for years because they are too wet. Buckwheat has been grown in field D in dry years, and some swale hay has been cut from field I. For practical purposes, however, they have been nonproductive land. In former years field D could not be drained alone because the only possible outlet was north thru field I and the owner of that field would not cooperate in putting a tile thru his own field. Since both fields are now owned by the same man, they can be easily drained by a few lines of tile. Most of this tile is already laid, and when the drain is completed the land will be the best on the farm.

The irregular area of night pasture as planned would include a strip of heavy clay soil which cannot be profitably tilled. Fields G, H, and I of the new plan would be kept in alfalfa continuously. This land is too rough to be cultivated to advantage, but it will grow alfalfa.

The tenant house at present located near the orchard R would be moved nearer to the main farmstead as shown. The worthless apple orchard R would be cleared off, and the remainder of the ditch in this field would be tiled so that this area of nearly 50 acres could be worked in two oblong fields.

This rearrangement, while far from ideal as stated above, represents an improvement over former conditions. Combining these farms has made possible the drainage of two formerly useless fields and has added 20 acres of good land to the crop area. The larger fields would result in greater efficiency of labor. No great expense is called for in the changes planned. They could be made in a few years, and the savings made possible should soon pay the cost of the changes.

POSSIBLE REARRANGEMENT OF A WESTERN NEW YORK FARM

The plan of a western New York farm as it existed in 1915 is shown in figure 158. The topography is level. The principal crops grown are beans, wheat, hay, alfalfa, corn, oats, and barley. Most of the land is tillable and therefore there is little permanent pasture. In addition to a herd of two or three cows, a few sheep are kept, and either lambs or steers are fattened in the winter to use up bean pods and other roughage. In

1915 field K of the crop land was pastured, in addition to the small area of permanent pasture, field I.

The layout of this farm was fairly good considering natural obstacles. There were ten crop fields in 1915, averaging 8.8 acres each in size and reasonably convenient to the buildings. The irregular shape of the fields was caused by a large open ditch which drained a considerable area of the land. This farm was made up of three parts, as its outline indicates.

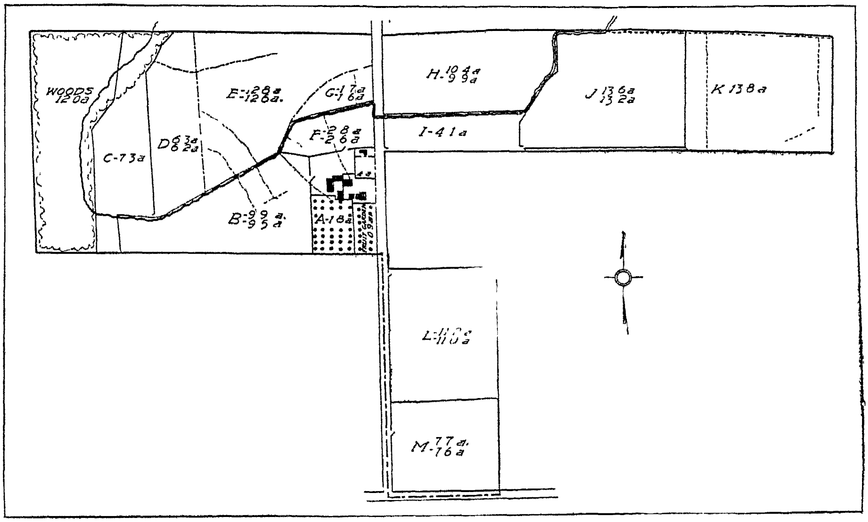


FIG. 158. PLAN OF A WESTERN NEW YORK FARM IN 1915

Farm area, 121.3 acres
Average size of farmed fields, 8 7 acres
Average distance to farmed fields, 60 rods

In 1916 the owner sold about 20 acres of his farm, and bought the run-down 90-acre farm adjoining his own on both sides of the road. The area sold comprised the fields L and M of the 1915 plan. These fields adjoined a neighbor's barn, and the owner was able to sell them to excellent advantage. They were bounded by a road on two sides, 7 per cent of their area thus being made untillable. The plan of the combined farms as they appeared in 1916 is shown in figure 159. The newly bought farm had been owned by an old man who had rented a considerable proportion of the land for several years. The farm was divided into eight rather small

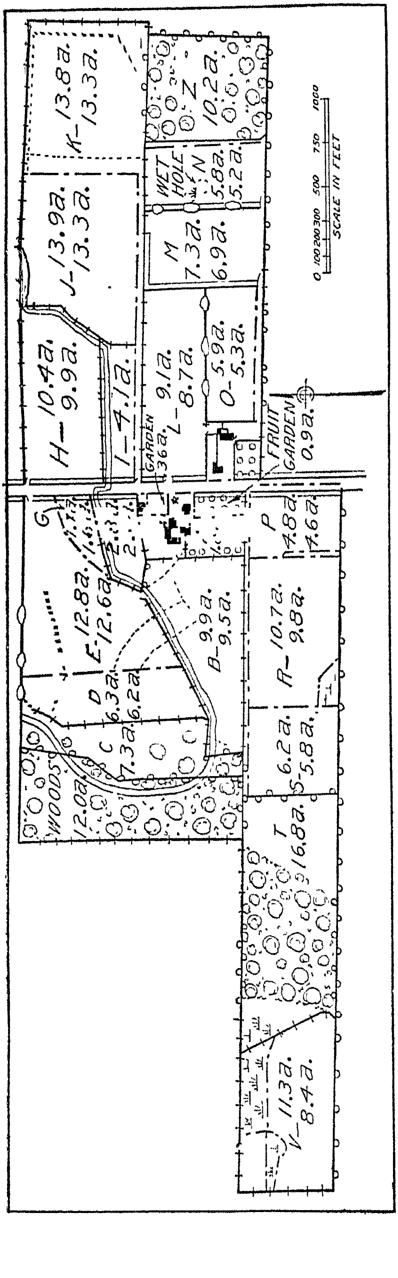


FIG. 159. PLAN IN 1916 OF FARM SHOWN IN FIGURE 158.

In 1915 fields L and M of the plan shown in figure 158 were sold and the 90-acre farm adjoining the former farm on the south was purchased

Farm area, 193.1 acres
Average size of farmed fields, 7.4 acres
Average distance to farmed fields, 73 rods

crop fields, separated by wide hedgerows of brush and stone. The present owner has already begun the work of clearing up the farm and enlarging the fields. In 1917 the swamp hole in field R was tiled and the hedgerow between fields P and R was cleared out. By making these changes, fields P, R, and S were combined into one field of 21 acres, which was sowed to wheat in the fall. The fence between fields J and K has been taken out, and these fields will be farmed as one field of about 27 acres. Other changes will be made as rapidly as is possible without interfering with the farm work.

A possible rearrangement of this farm is shown in figure 160. This plan would provide for seven crop fields — three fields of about 27 acres each for the major rotation, three fields of 8 acres each for a minor rotation, and one field for alfalfa. The major rotation would be the common one in this region, consisting of beans, wheat, clover. The minor rotation would be silage corn, oats, wheat. In this section of the State, where little hay is needed for feed and other crops are more profitable for sale, there is a tendency to shorten rotations by omitting hay. Clover is seeded with wheat, but, instead of being cut, is plowed under in the spring for corn or potatoes. The advantage of the cropping system outlined is that corn silage wanted for feed will be grown in fields near the barn.

Field A in the proposed rearrangement would be formed by combining fields J and K of the present layout. Field B would be formed by combining fields L, M, N, and O. This would require clearing a considerable amount of brush and stone fence rows and would take some time. Possibly these stones might be disposed of for use on an improved road. Field C would be formed by combining the present fields P, R, and S, and taking in some of the tillable land in the adjoining pasture. The present crop field V, too wet and too remote for profitable farming, would be pastured or sold to the farmer near whose house it is located. The arrangement of fields D, E, and F is based on the assumption that the present open ditch can be tiled. The owner is planning to tile this ditch if it can be done without too great expense. The improvement in the shape of the fields, the elimination of the labor of keeping the ditch clear, and the saving of land, would be worth considerable effort and expense. If the ditch cannot be economically tiled, the shape of the fields of the minor rotation would not be so good but the proposed rearrangement would not be affected otherwise.

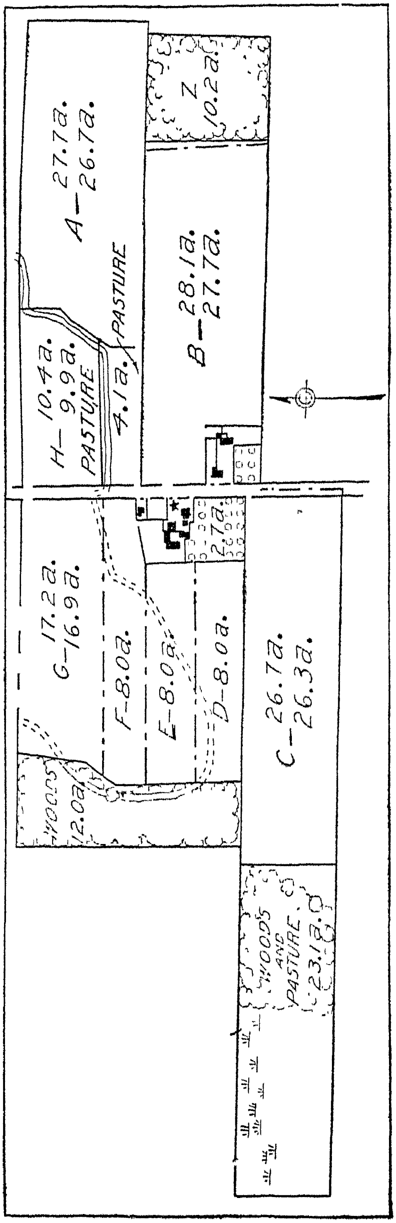


FIG. 160. A POSSIBLE REARRANGEMENT OF THE FARM SHOWN IN FIGURE 159

Farm area, 193.1 acres
Average size of farmed fields, 17.4 acres

The woodlot Z contains no valuable timber, and occupies level tillable land which will eventually be added to the crop land. Already a strip along the north side which shaded the adjoining crop fields has been cut. Crop land in this region is worth from $100 to $125 an acre.

By the changes suggested a good field arrangement would be secured in a few years. The changes already made have resulted in a great improvement. By selling off two of the more distant fields and buying land nearer to the buildings, the layout of two farms was improved. The buildings of the present farm are as near the center of the crop area as is possible with farms of this shape. The saving of labor and land made possible by the further improvement in arrangement as suggested, would in a few years pay the cost of making the changes.

LAND UTILIZATION

A complete inventory of the land on the farms included in these studies is presented in table 32. The areas given under the different headings will not check in all cases with corresponding areas in previous pages.

TABLE 32. INVENTORY OF LAND ON FIFTY-THREE NEW YORK FARMS

	Total number of acres	Number of acres per farm	Per cent of total farm area
Farmsteads:			
Home gardens	15 98	0 30	0 17
Home orchards:			
Apple	40.54	0.76	0 44
Mixed fruit	2.90	0 05	0 03
Total home orchards	43.44	0.82	0 47
Other farmstead crops	2 63	0.05	0 03
Paddocks	12 69	0 24	0 14
Land occupied by buildings, lawns, etc	88.28	1.67	0 96
Total farmsteads	163 02	3 08	1.77
Tenant houses:			
Gardens	13.28	0 25	0 14
Orchards	1 32	0 02	0 01
Land occupied by buildings	19 64	0.37	0 21
Total area tenant houses	34.24	0 65	0 37

TABLE 32 (*continued*)

	Total number of acres	Number of acres per farm	Per cent of total farm area
Public roads not in crops	144.75	2.73	1.57
Woodland not pastured:			
Tillable if cleared	151.89	2.87	1 65
Could be made tillable	64.33	1.21	0.70
Not tillable:			
Suitable for pasture	22.30	0.42	0.24
Suitable only for woodland	22.58	0.43	0.25
Total not tillable	44.88	0.85	0.49
Total woodland not pastured	261.10	4.93	2 84
Permanent pasture other than paddocks:			
Cleared pasture:			
Tillable:			
Lanes	17.46	0.33	0.19
Other land	187.77	3.54	2.04
Total tillable pasture	205.23	3.87	2.23
Could be made tillable:			
Lanes	6.20	0.12	0.07
Other land	840.31	15.85	9.14
Total cleared pasture which could be made tillable	846.51	15.97	9.21
Not tillable	542 37	10.23	5.90
Total cleared pasture	1,594.11	30.08	17.34
Woodland pastured:			
Tillable if cleared	395.79	7.47	4.31
Could be made tillable	89 83	1.69	0.98
Not tillable:			
Suitable for pasture	297.09	5.61	3.23
Suitable only for woodland	98.78	1.86	1.07
Total woodland pastured not tillable	395.87	7.47	4 31
Total woodland pastured	881.49	16.63	9.59
Total permanent pasture	2,475 60	46.71	26.93

TABLE 32 (*continued*)

	Total number of acres	Number of acres per farm	Per cent of total farm area
Land in cropped fields (other than gardens and farmstead crops):			
Land in cropped fields not producing a crop:			
Fence rows	102 28	1.93	1 11
Swampy land	30.34	0.57	0 33
Streams	24 46	0 46	0 27
Open ditches	12 66	0 24	0 14
Driveways in crop fields	11 43	0 22	0 12
Rough or steep land	11 27	0.21	0 12
Land shaded by woodlots	6 68	0 13	0 07
Trees in fields	5 25	0.10	0 06
Stone outcrops	2 17	0 04	0 02
Barns in fields	2.15	0 04	0 02
Stone piles	1 42	0 03	0 02
Total land in cropped fields not producing a crop	210 11	3 96	2 29
Land in cropped fields producing a crop:			
Crops other than fruit:			
Not rotated:			
Permanent meadow	106 07	2 00	1.15
Rotated:			
General crops	4,413 87	83 28	48 02
Truck crops	88 38	1 67	0 96
Rotated pasture	645 85	12.19	7 03
Total rotated	5,148 10	97 13	56 01
Total crops other than fruit	5,254 17	99 14	57.17
Fruit (other than home orchards):			
Apples:			
Bearing	247 45	4 67	2 69
Not bearing	150.35	2 84	1 64
Total apples	397 80	7 51	4 33
Peaches:			
Bearing	37 53	0 71	0.41
Not bearing	16 17	0 31	0 18
Total peaches	53 70	1 01	0 58
Pears:			
Bearing	25 70	0.48	0 28
Not bearing	7 82	0 15	0.09
Total pears	33.52	0 63	0.36

TABLE 32 *(concluded)*

	Total number of acres	Number of acres per farm	Per cent of total farm area
ıd in cropped fields (other than gardens and farmstead crops) *(continued)*:			
.and in cropped fields producing a crop *(continued)*:			
Fruit (other than home orchards) *(continued)*:			
Plums or prunes, bearing	7.23	0.14	0 08
Cherries:			
Bearing	6.02	0.11	0.07
Not bearing	0.90	0.02	0.01
Total cherries	6.92	0.13	0.08
Grapes:			
Bearing	22.28	0.42	0 24
Not bearing	7.02	0.13	0.08
Total grapes	29.30	0.55	0.32
Mixed fruits, bearing	3 44	0.06	0.04
Roadside apples:			
Bearing	1.90	0.04	0.02
Not bearing	2.12	0.04	0 02
Total roadside apples	4 02	0.08	0.04
Total fruit other than home orchards	535.93	10.11	5.83
tal crops (including fruit)	5,790.10	109.25	63.00
tal land in cropped fields (other than gardens and farmstead crops)	6,000.21	113.21	65.28
her land:			
Lanes not included in pasture or cropped fields	15.67	0.30	0.17
Pasture land occupied by streams	23.97	0.45	0.26
Land other than pasture or crop land occupied by streams	26.80	0.51	0 29
Steep land not in cropped fields	25 33	0.48	0 28
Brushlot (waste)	11.36	0.21	0.12
Unused farmsteads	5.01	0.09	0.05
Village lots	4 00	0.08	0.04
Total other land	112 14	2.12	1 22
tal area of farms	9,191 06	173.42	100 00

This is due to the fact that some classes of land have heretofore been included under two different classifications. For example, woodland pasture was included as woodland in table 27 (page 495) and also as pasture in table 25 (page 491). Home gardens and orchards were likewise included in the study of land in farmsteads and also in the study of land in crops. In table 32 there are no duplications.

A comparison of the present use of land on these farms with that on the average New York farm is given in table 33. Not only are the farms

TABLE 33. COMPARISON OF THE PRESENT USE OF LAND ON THE FARMS STUDIED, WITH THAT ON THE AVERAGE NEW YORK FARM

	Number of acres per farm		Per cent of total farm area	
	Average of 185,051 farms in 1918 census of New York	Average of 53 New York farms studied	185,051 New York farms	53 New York farms studied
Crops other than fruit	45 61	94.17	44.21	54 30
Fruit	3.22	10 11	3.12	5.83
All crops	48.83	104 28	47.33	60 13
Tillable pasture	12 34	8 84	11 96	5 10
Other cleared pasture	12.96	26 21	12 56	15 11
Total cleared pasture	25 30	35.05	24 52	20 21
Woods pastured	11 55	16.63	11.20	9 59
Total pasture	36.86	51.68	35.73	29.80
Woods not pastured	10.81	4 93	10.48	2 84
Farmsteads, roads, and lanes	3 83	12.53	3 71	7 23
Use not reported	2 84	....	2 75	.....
Total farm area	103 17	173.42	100 00	100 00

included in these studies much larger than the average, but they have a larger proportion of their land in crops and a smaller proportion in pasture than do the farms reporting in the last census of New York agriculture.[3]

[3] Census of the agricultural resources of New York. Census of 1917 taken by order of the New York State Food Supply Commission. Census of 1918 taken by order of the New York State Food Commission. 1919.

Sixty per cent of the area of these farms was in crops, as compared with 47 per cent for the State. About 30 per cent of the area of these farms was in pasture, as compared with nearly 36 per cent for the State. The proportion of the land in woods not pastured was much lower on the farms included in these studies, 2.84 per cent, as compared with 10.48 per cent for all farms reporting in the census. The proportion of the area of the farms here considered in farmsteads, lanes, roads, fence rows, and other obstructions, is approximately equal to the sum of the percentage of land so classified and of land with use not reported in the census.

The relation of size of farms to the proportion of land producing crops is shown in table 34:

TABLE 34. RELATION OF SIZE OF FARMS TO PROPORTION OF LAND PRODUCING CROPS

	Size of farms (acres)			
	Less than 100	100 to 174.9	175 or more	All farms
	Per cent of total farm area			
Land producing a crop:				
Crops other than fruit:				
Home gardens	0.28	0.27	0.11	0.17
Other farmstead crops	0.09	0.02	0.02	0.03
Tenant gardens	0.07	0.10	0.18	0.14
Permanent meadows	1.48	0.56	1.36	1.15
Rotated crops	53.57	60.53	54.41	56.01
Total crops other than fruit	55.49	61.47	56.08	57.50
Fruit:				
Home orchards	0.50	0.57	0.43	0.47
Tenant orchards	......	....	0.02	0.01
Other fruit	18.38	7.02	3.10	5.83
Total fruit	18.88	7.59	3.55	6.31
Total cultivated crops	74.37	69.06	59.63	63.81
Permanent pasture:				
Cleared pasture	9.57	16.82	19.17	17.48
Woodland pasture	5.35	3.78	12.95	9.59
Total permanent pasture	14.92	20.60	32.12	27.07
Woodland not pastured	2.35	2.13	3.25	2.84
Total land producing a crop	91.64	91.79	95.00	93.72

TABLE 34 (*concluded*)

	Size of farms (acres)			
	Less than 100	100 to 174.9	175 or more	All farms
	Per cent of total farm area			
Land not producing a crop:				
Main farmstead occupied by buildings	1.99	1.11	0.71	0.96
Land occupied by tenant houses	0.22	0.11	0.26	0.21
Public roads not in crops	1.48	1.77	1.50	1.57
Land in cropped fields occupied by:				
Fence rows	1.48	1.14	1.04	1.11
Swampy spots	0.52	0.59	0.19	0.33
Streams	0.36	0.24	0.26	0.27
Open ditches	0.12	0.25	0.09	0.14
Driveways	0.32	0.15	0.08	0.12
Rough or steep land	0.26	0.24	0.05	0.12
Land shaded by woods	0.11	0.06	0.07	0.07
Trees in fields	0.01	0.01	0.08	0.06
Stone outcrops	0.12	0.01	....	0.02
Barns in fields	0.01	0.03	0.02	0.02
Stone piles	0.01	0.02	0.02	0.02
Total land in cropped fields not producing a crop	3.32	2.74	1.90	2.29
Lanes not included in pasture or cropped fields	0.19	0.22	0.15	0.17
Pasture land occupied by streams	0.01	0.58	0.16	0.26
Land other than pasture or crop land occupied by streams	1.01	0.31	0.16	0.29
Steep land not in cropped fields	....	0.94	0.02	0.28
Brushlot	....	0.45	....	0.12
Unused farmsteads	0.13	....	0.07	0.05
Village lots	....	....	0.07	0.04
Total land not producing a crop	8.35	8.23	5.00	6.24

Nearly 94 per cent of the land in these farms was producing some kind of a crop, either field crop, garden, orchard, pasture, or woods. While the value of these different crops varies widely, they are all contributing directly, in some measure, to the farm income. The remainder of the land in these farms, 6.24 per cent, was not producing a crop. Most of this land was not wasted because it was necessary to the proper organization of the business, but it contributed nothing directly to the farm

income. The greater proportion of the land not producing a crop was occupied by obstructions in crop fields, farmsteads, public highways, and tenant houses.

A study of these farms indicates that the area of land suitable for cropping can be considerably increased if conditions warrant. Altho most of the good agricultural land in America is now in farms, the productivity of farms can be greatly increased by a more intensive utilization of land. A proper utilization of land infers not only that as large a proportion of the land as possible shall be productive, but that the land shall be devoted to the purpose which pays best. Farmers are not now making the maximum utilization of their land because it is not profitable to do so.

Some ways of increasing the crop area on the farms studied are pointed out in table 35:

TABLE 35. POSSIBLE INCREASES IN THE CROP AREA OF FIFTY-THREE NEW YORK FARMS

	Total number of acres	Number of acres per farm	Per cent of total farm area
Public roads on which roadsides could be tilled	30.00	0.57	0.33
Woodland not pastured:			
Tillable if cleared	151.89	2.87	1.65
Could be made tillable, after clearing, by drainage	48.94	0.92	0.53
Could be made tillable, after clearing, by removing stones	15.39	0.29	0.17
Total woodland not pastured that could be tilled	216.22	4.08	2.35
Woodland pastured:			
Tillable if cleared	395.79	7.47	4.31
Could be made tillable, after clearing, by drainage	89.83	1.69	0.98
Total woodland pastured that could be tilled	485.62	9.16	5.28
Cleared pasture other than lanes and paddocks:			
Tillable	187.32	3.53	2.04
Could be made tillable by drainage	353.19	6.66	3.84
Could be made tillable by clearing away stones	292.92	5.53	3.19
Could be made tillable by clearing away stones and brush	61.30	1.16	0.67
Could be made tillable by clearing away stones and by drainage	132.90	2.51	1.45
Total cleared pasture, other than lanes and paddocks, that could be tilled	1,027.63	19.39	11.18

TABLE 35 (*concluded*)

	Total number of acres	Number of acres per farm	Per cent of total farm area
Fenced driveways not used for stock, which could be tilled	8 00	0 15	0.09
Crop land occupied by obstructions:			
Fence rows	35.28	0.67	0.38
Open ditches	8 35	0 16	0 09
Streams	9 85	0 19	0.11
Swampy spots	31.00	0.58	0.34
Stone piles	1 08	0.02	0 01
Trees in fields	5.25	0 10	0 06
Land shaded by woodlots	6.68	0 13	0 07
Rough land	2 26	0.04	0 02
Driveways in crop fields	2 15	0.04	0 02
Barns in crop fields	0 75	0.01	0 01
Total crop land occupied by obstructions, which could be tilled	102.65	1.94	1.12
Other land that could be tilled:			
Brushlot	11 36	0 21	0 12
Unused farmsteads	5 01	0 09	0 05
Total other land that could be tilled	16 37	0 31	0 18
Total land that could be added to crop area	1,886.49	35 59	20.53
Present area of all crops	5,866 75	110 69	63.83
Possible future area of all crops	7,753 24	146 29	84 36
Total area of farms	9,191 06	173 42	100 00

By rearranging these farms so as to reclaim as much as possible of the land that is now unproductive, about 157 acres could be added to their crop area. This would be an increase of 3 acres of crop land to each farm, or an increase of 2.7 per cent in the crop area. This increase would come out of land which is now unproductive because it is occupied by unnecessary fences, swampy spots, and other obstructions, and would not decrease either pasture or woodland. Probably the land gained would seldom pay for the expense of rearrangement, but the saving of labor is usually more important than the land gained. Where unnecessary stone fences

can be used for improving roads, a threefold saving results: the removal of the stones permits the enlarging of fields and thereby saves labor in growing crops, the improvement of the roads saves labor in marketing the crops, and some land is gained for crop production.

If, in addition to the foregoing changes, all woodland suitable for crop production or for pasture were cleared, about 700 acres could be added to the crop land of these farms without decreasing the effective area of permanent pasture. This would mean an increase of 13.2 acres of crop land to each farm, or an increase of 11.9 per cent of the crop area, but it would decrease the farm wood and lumber supply about 90 per cent. The area of woodland to each farm would be reduced from 21.5 acres to 2.3 acres. In addition to this woodland which is good for no other purpose, some trees might be grown in the pastures.

If as much as possible of the unproductive land on these farms were reclaimed, if all woodland suitable for other purposes were cleared, and if all land suited to crop production were used for that purpose, the area of crop land could be increased about 1886 acres. This would be an increase of 35.6 acres to each farm, or an increase of about one-third in the crop area at the expense of the area of woodland and pasture. As in the preceding case, the area of woodland to each farm would be reduced from 21.5 acres to 2.3 acres, this woodland being suitable for no other purpose. This rearrangement would also reduce by one-half the effective area of permanent pasture, leaving but 17 acres of cleared permanent pasture to each farm. The changes would reduce the farm supply of wood and lumber, and, unless some change were made in the system of farming, would necessitate a reduction in the amount of livestock kept.

Increasing the crop area will mean, not cheaper food, but higher-priced food, because low prices would not justify the expense involved in making these changes. It is better to have more food, even at a higher price, than not to have food when it is needed. Clearing land for cultivation is a long and laborious process. After the trees are cut, it takes about ten to twenty years for the stumps to rot so that the land can be cleared cheaply. In most cases it is better to pasture the land while the stumps are rotting than to clear at once. While, in a general way, the land adapted to crop production will be added to the crop area when conditions justify the addition, the response to these conditions is neces-

sarily slow. At the present time some woodland occupying valuable tillable land is being cut over and will eventually be added to the crop area. Probably there are more farmers who own woodland occupying tillable land too valuable for forestry purposes, who should be thinking about making similar changes.

But land must have another advantage besides being tillable before it will be cropped. It must be near enough to its owner so that it can be cropped economically. Much land now in tillable pasture would be cropped if it were not too remote from its present owner. Such land is usually near enough to some one to be cropped to advantage. Readjustments in ownership which would permit each farmer to farm the land most convenient to his buildings would be desirable from a public as well as from a private point of view. In most cases such readjustments can now be made only with difficulty.

SUMMARY

This memoir reports the results of a study of the layouts of fifty-three New York farms, the object being to trace the development of farm layouts, to study the principles of efficient farm field arrangements, and to study the utilization of land on these typical farms with particular reference to the possibilities of increasing the area of crop land to meet the needs of an increasing population.

Most of the farm land of New York was originally covered with forests. A large part of this land was divided into farms and cleared for farming when hand-labor methods of agriculture prevailed. Subsequent changes in economic conditions and in methods of agricultural production, and their consequent effect on farms and farming, have given rise to most of the present problems of farm layout. Changes in farm layout have not kept pace with changing agricultural conditions, and as a result most farms now need rearranging. Plans of farms here shown illustrate the historical development of the layout of typical New York farms.

Large crop fields give greater economy of labor, fencing, and land. Hence farmed fields should be as large as the size of farm, the type of farming, the length of rotation, and physical factors, will permit.

For crop fields of ordinary size the oblong shape gives the most efficient use of labor, while the square shape is the most economical of fencing and of land. Saving labor is usually more important than saving land and

fencing, and therefore oblong shapes are most desirable for crop fields of moderate size. Very large crop fields may be square to save fencing, and yet be long enough to permit the efficient use of labor.

The distance from farmstead to fields should be made as short as possible in order to save useless travel. With farms of moderate size the farmstead should be located as near the center of the farm as it can be placed and still be on the highway. The ideal arrangement is to have half of the land on each side of the highway, with the buildings in the center of the farm.

Crop fields should be free from obstructions, such as swampy spots, open ditches, streams, trees, stone piles, and unnecessary fences.

The question of fencing farms suitably and economically is becoming increasingly important. Data are herein presented showing the amount of each kind of fencing found on these farms, the adaptation of fencing practice to local conditions in different parts of the State, the distribution of fence on farms, the proportion of farm division lines that are fenced, the relation of size of farm to economy of fencing, the amount of land occupied by fences, the proportion of the farm area inclosed by fence, and the farm cost of fence maintenance.

Farm lanes and driveways should be carefully planned for efficiency of labor, fencing, and land. The area of land utilized in lanes on the farms studied is given, as well as the average width of lanes with different amounts of stock.

The proper utilization of farm land is also important. Data are presented showing the amount of land in cropped fields occupied by fences, swampy spots, streams, and other obstructions, and by different classes of crops, on the farms studied, the relation of size of farms to the proportion of the area of cropped fields occupied by obstructions, the classification of pasture land, the relation of size of pastures to economy of fencing, the classification of woodland, and the present use of land in highways and farmsteads.

Many farm plans are given illustrating desirable and undesirable features of farm layouts. These plans emphasize the fact that most farms need rearranging to adapt them to present conditions.

In addition to the preceding factors, physical features such as soil, drainage, and topography should also be considered in planning a farm layout.

The logical procedure in planning the rearrangement of a farm is:

1. To study carefully the farm and the local conditions.
2. To decide on the cropping plan or rotation.
3. To make a plan for the long-time development of the farm which will provide as good a layout for the conditions as the natural limitations permit.
4. To carry out plans slowly, doing the work at odd times; to do the most important things first; not to let this work interfere with work on crop production.

Plans are included in the bulletin illustrating different stages in the actual rearrangements of some New York farms as made by owners, and possible rearrangements of other farms which have been started but are not yet completed. These plans are accompanied by descriptions of the farms, of local conditions, and of the procedure followed in carrying out the plans for rearrangement.

A complete inventory of the land on these farms is given, showing the present use of all land. Data are presented comparing the use of land on these farms with that on the average New York farm, and also showing possible increases in the crop area of the farms studied by reclaiming land now unproductive and by utilizing for crops land which is now occupied by pasture or woods but which would be suitable for crop production. If the farms studied may be considered as typical, substantial increases can be made in the crop area of New York farms to meet the prospective needs of an increasing population.

Memoir 31, *A Study of Selections for the Size, Shape, and Color of Hens' Eggs*, the third preceding number in this series of publications, was mailed on August 21, 1920.

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RESISTANCE OF THE ROOTS OF SOME FRUIT SPECIES TO LOW TEMPERATURE

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CONTENTS

RESISTANCE OF THE ROOTS OF SOME FRUIT SPECIES TO LOW TEMPERATURE

RESISTANCE OF THE ROOTS OF SOME FRUIT SPECIES TO LOW TEMPERATURE[1]

D. B. Carrick

There are several types of winter injury to fruit plants which are of more or less frequent occurrence in New York State. Among these may be mentioned injury to small twigs, especially those of peach trees and of tender apple varieties such as Tompkins King; injury to the winter buds and sometimes to the blossoms; sun-scald, and the rather closely related forms of crotch injury and crown rot; and injury to the roots. Perhaps the killing of the roots by low temperature should be associated with the less serious types of winter injury in this State, due in part to the fact that it occurs in restricted areas. Yet in the Champlain Valley and in the upper Hudson River section, the freezing of the roots is one of the important problems in fruit production. This is also the case in parts of New England, in Canada, and in a number of the Western States.

The work reported in this paper was begun in the fall of 1915 and extended thru the spring of 1917. An attempt has been made to determine approximately under standard conditions the range of variation and the relative hardiness of some of the more commonly grown fruit stocks, including a few varieties of the small fruits. Some data were also obtained regarding the influence of certain factors on the freezing to death of plant tissue.

Careful field studies and the testing of possible fruit stocks capable of withstanding severe cold are significant aspects of the question that have not been attacked. It is hoped, however, that some of the results presented here may be suggestive in the working out of these other phases of the problem of root injury by low temperature.

REVIEW OF THE LITERATURE

Craig (1900) observed extensive winter injury to the roots of apple, plum, and cherry in Iowa. The one- and two-year-old apple trees in the

[1] Also presented to the Faculty of the Graduate School of Cornell University, in August, 1917, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

Author's acknowledgments [illegible] acknowledge his indebtedness to Professor W. H. Chandler for the direction of this w[illegible] criticisms given during its progress.

nursery were almost completely destroyed. In the orchard, apple trees from three to fifteen years old, situated on a north slope on light soils and unprotected by snow or vegetation, suffered very severely. It was noted, however, that hardy varieties rooted from the scion often withstood the same cold that killed trees which were wholly on seedling roots. The varieties least injured were: first, Siberian crab apple; second, native crab apples and the Hibernal type of Russian apples; and third, varieties of western origin such as Northwestern.

The most resistant plum stock seemed to be *Prunus Besseyi*. No injury in any case was found in this species. *Prunus americana* was the next in resistance, being only slightly injured. Marianna roots were seriously damaged, while Peach and Myrobalan roots were entirely killed.

The hardiest cherry root observed was the Morello stock, which, except where exposed, escaped with slight injury. Trees in the nursery on Mazzard stock were practically a total loss, while those on the Mahaleb stock suffered less.

From the foregoing observations Craig concluded that the absence of snow or other protective covering during an unusually severe winter accounted for the very considerable root injury. To prevent a recurrence he advocated the use of desirable cover crops, the employment of the hardiest stocks available, and the deep planting of young trees, especially on the loess soils of the State.

Emerson (1903) conducted an interesting experiment to determine the influence of mulching and soil moisture on the freezing of roots. He filled seven boxes, 2 feet square and 18 inches deep, with a loam soil, and planted twenty-five apple seedlings in each box.

In the box protected by a 4-inch straw mulch, there was a soil moisture content of 16 per cent. By this treatment no roots were found dead and but seven were injured. In the box covered occasionally with snow and containing 15.8 per cent of moisture, seven roots were dead and eight were injured. In the unprotected boxes the injury seemed to vary inversely with the increased water content of the soil. With 10.4 per cent of moisture the roots of twenty trees were dead and five were uninjured; with 25.6 per cent of moisture, eight roots were dead, four were injured, and thirteen were uninjured. Not a root was injured in a box stored in a cool, dry place, altho its soil contained only 10 per cent of moisture.

Emerson (1906) found some striking differences in the protection of certain cover crops against deep freezing. In one case in which the snow was held, the ground froze to a depth of six inches where corn was planted, twelve inches with a heavy cover of oats, fifteen inches under a medium heavy crop of millet, and twenty-four inches where the soil was bare. These facts suggest the use of cover crops which will catch and hold the snow in regions where root injury is prevalent.

Macoun (1908) mentions the killing of roots as one of the ten forms of winter injury occurring in Canada. He recommends the use of cover crops as a means of increasing the soil moisture and holding the snow. His observations on the effect of soil moisture were similar to the experience of Emerson. He states also that the grafting of apples on the garden crab-apple trees has somewhat reduced the root injuries due to freezing.

By means of careful artificial freezings, Chandler (1913) obtained a considerable amount of interesting data on the relative hardiness of various fruit stocks. He found that the range of killing temperature of apple, peach, pear, and plum roots was from –3° C. in summer to –12° in late winter with rather rapid freezing. He compared the killing temperature of apple roots actively growing in the greenhouse with that of dormant ones in cold storage, in basement storage, and outside in frozen soil, respectively. The three dormant treatments showed little difference in resistance, but the active tissues killed at three centigrade degrees higher than did the dormant roots. Similar comparisons of peach and Marianna plum roots showed somewhat less variation between the conditions of growth and dormancy.

Chandler observed also a diminished hardiness in the roots farthest from the crown, apparently varying with their soil depth. He demonstrated further that in most cases the roots coming from the scions of Ben Davis apple trees were hardier than similar roots from French apple seedlings. An extended laboratory determination of the comparative resistance of Marianna and Myrobalan plum roots and Mahaleb and Mazzard cherry stocks strongly confirmed Craig's observations under orchard conditions.

Mix (1916), while studying sun-scald in the northern part of the Champlain Valley, New York, observed a great amount of winter injury in the roots of apple trees from one to twenty years old. The injured condition

seemed most serious where fall plowing was practiced and where the trees were on light soils and in windy situations. The Ben Davis trees were especially susceptible, from 50 to 75 per cent of these being left in a dying condition. Northern Spy and Wealthy trees also were injured, but in a degree much less than the Ben Davis. Mix observed also some cases in which, as he states, "the hardiness of the stock seems to have been influenced by the scion."

METHOD USED IN FREEZING THE ROOTS

The apparatus used in this study for freezing the roots consisted of: an inner chamber of galvanized iron 9 inches long, 1½ inches wide, and 30 inches deep; an outer chamber of the same material, 6 inches long, 12 inches wide, and of the same depth as the inner chamber; and around the outer chamber, 5 inches of insulation held in place by a casing of wood. The roots to be frozen were placed in the inner compartment, and were surrounded by the freezing mixture of ice and common salt in the second chamber. At no time was the actual tissue temperature determined, but the temperature of the air around the tissues was measured by means of three electrical resistance thermometers and a balance indicator. The latter instrument consisted of the circuit of a Wheatstone bridge mounted in a suitable case with a galvanometer and means for balancing the bridge by moving a contact along a slide wire.[2] The three electrical resistance bulbs, each with leads 5 feet long, were used until the variation in temperature in the lower part of the freezing chamber was determined. These bulbs were standardized by the makers and were carefully checked against one another in the laboratory here. The bulbs were securely attached to a piece of hardware cloth 6 inches square. The various roots to be tested were fastened to this wire by means of rubber bands. The bulbs always stood perpendicular to the bottom of the chamber, and the roots were always arranged on the cloth parallel to the bulbs.

Careful tests showed that, while the temperature was uniform at given levels within certain limits, it varied slightly at different levels. Because of this fact, a complete record as to the injury in the lower and in the upper ends of the roots was kept. To further standardize this variation, all of the pieces of material used were cut 4 inches in length. When the

[2] This is a standard apparatus obtainable from the Leeds, Northrup Company, of Philadelphia.

hardware cloth and the bulbs were in position, the roots extended to within one inch of the bottom of the chamber in a regular row.

The difference in temperature on either side of a bulb — that is, horizontally — within a compass of five inches was found to be negligible. However, a number of tests of the temperature in either extreme end of the freezing chamber showed that a maximum difference of one centigrade degree might exist. Accordingly, no roots were tested at these points.

In order to subject all the material to as nearly uniform conditions of freezing as were possible, the killing temperature of a number of different roots was determined at the same time rather than an attempt being made to freeze at once many roots of a single sort. Owing to the variety of roots used, however, it was neither practicable nor desirable to test all of these at any one time. As they naturally divided themselves into groups of more or less tenderness, material of similar resistance was usually frozen together.

While the temperature was being gradually lowered, the inner compartment was kept tightly closed. In no case were any of the roots removed before the minimum degree was reached.

Since several workers have found a distinct influence in the amount of injury resulting from the rapidity of cooling, care was taken to allow a standard rate of fall for all freezings, except as noted to the contrary. This uniform lowering of temperature began at 1.5° C., and reached 0° in fifteen minutes. The fall from this point to the desired degree was at the rate of one degree every twenty-two and one-half minutes. The minimum temperature was always maintained for fifteen minutes. Ordinarily the roots were removed from the chamber and allowed to thaw rapidly.

Russell (1914) and others have noted that the death of a plant from freezing is rarely immediate but may be delayed for several days. Because of this possibility the treated roots were set aside and examined at different intervals. During this time they were kept moist by placing them on a hardware cloth which projected above the surface of the water in an agate pan. The roots and the pan were covered with a bell jar.

An inspection of the roots for injury was usually made within from one to three days after exposure. In most cases when injury occurred, it was apparent by the end of this period. At first microtome sections were prepared and the character of the injury was determined with a low-

power microscope. This was soon found to be unnecessary, since the color changes of the frozen cells, except in the gooseberry and the currant, were rather striking. The affected tissues of the apple became of some shade of brown and appeared water-soaked; in Mazzard cherry, Myrobalan plum, and red raspberry roots, the injured cells were somewhat yellowish; while in the blackberry and the dewberry they often appeared almost black. The early appearance of Rhizopus species and probably other saprophytic fungi on the dead part was also characteristic of injury. In not an instance did the fungus or the discoloration appear in the unfrozen roots left similarly located for comparison.

The roots of all species tested from October 24 to November 18 were collected from the nursery row. All the leaves were present on the plants used in the first determinations and some had not fallen in the latter freezings. The remainder of the material was kept in common storage and removed as needed. With this material the temperature varied somewhat, due to outside changes, but it seldom went below 0° C. and did not rise above 5° until April 1. The plants were stored in normally moist sawdust, and there was little opportunity for them to dry out later as they were placed on the hardware cloth attached to the resistance bulb while in storage and were then immediately frozen.

RESULTS OF THE EXPERIMENTS

RESISTANCE OF APPLE ROOTS TO LOW TEMPERATURE

For all the tests conducted, the diameter of each end and of the center of the root, and the date of freezing, are recorded as possible factors that might influence the kind or the amount of injury. The results of the tests with apple roots are shown in table 1.

Four kinds of seedlings were used: one-year American stocks, grown in this country but from French seed; one-year French seedlings imported from France; two-year French roots which had grown for one year in the nursery here; and one-year stored French seedlings which had been held at approximately 0° C. in cold storage for one year.

One noticeable feature in the apple freezings was the differences in the individual resistance of roots similarly treated and frozen apparently under the same conditions. Unless the temperature is above or below the average freezing point, all gradations of injury may occur.

TABLE 1. EFFECT OF LOW TEMPERATURE ON ROOTS OF APPLE SEEDLINGS

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
						Cambium	Phloëm	Cortex
—7°	October 24 to November 18	American	7 x 6	2	2	....	....	......
			5 x 4	4	3	50	50	50
			4 x 3	7	......	40	40	40
		2-year French	7 x 5	10	10	....	....	......
			5 x 4	8	5	40	40	40
			4 x 3	6	....	60	50	50
—8°		American	5 x 4	1	1	..	....	......
			4 x 3	8	2	40	20	20
			3 x 3	1	.	50	50	50
		2-year French	7 x 5	3	3	.	....	....
			5 x 4	2	2	....	......	.....
			4 x 3	13	2	60	60	60
—9°		American	7 x 5	3	1	35	35	35
			6 x 5	2	....	25	25	50
			5 x 4	4	1	90	90	90
		2-year French	7 x 5	2	2	......	....	......
			5 x 4	6	......	75	75	75
			4 x 3	5	5	....	....	......
—9°	December to January	American	9 x 7	5	2	80	35	35
			6 x 6	4	1	50	45	45
			5 x 4	4	....	75	60	60
		2-year French	7 x 5	6	4	5	5	10
			5 x 3	6	2	35	20	20
			4 x 2	6	3	80	65	65
—10°		2-year French	7 x 5	5	3	45	15	15
			5 x 3	14	1	50	50	50
			4 x 3	11	...	60	60	60
—12°		2-year French	8 x 6	2	.....	5	5	5
			4 x 3	3	....	100	100	100
—9°	February to March	American	7 x 6	9	6	20	10	10
			5 x 4	9	4	60	60	60
		2-year French	8 x 5	3	3	....	......	.....
			3 x 2	3	.....	50	50	50

TABLE 1 (*continued*)

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
						Cambium	Phloëm	Cortex
—10°	February to March (*continued*)	American	7 x 6	12	10	65	10	
			5 x 4	8		50	50	45
			3 x 2	10		55	55	50
		2-year French	7 x 5	3	3			
			3 x 2	8	1	65	65	65
—11°		American	7 x 6	12	4	60	30	25
			5 x 4	6	2	55	55	55
			3 x 2	30	20	40	40	40
		2-year French	6 x 5	5	5			
			3 x 2	20	11	45	45	45
		1-year French	8 x 5	5				
			3 x 2	8	2	40	10	30
—12°		American	7 x 6	9	1	80	70	70
			5 x 5	11		85	85	85
			4 x 3	8		75	75	75
			3 x 2	22		80	80	80
		2-year French	6 x 5	5		75	75	75
			3 x 2	33		85	85	85
		1-year French	8 x 6	4	4			
			3 x 2	19	5		15	15
		1-year French, stored	8 x 5	4		100	100	80
			3 x 2	22	7	55	55	55
—12.5°		1-year French	8 x 6	4	1	50	50	50
—13°		American	7 x 6	8		90	90	90
			3 x 2	16	2	75	75	75
		1-year French, stored	3 x 2	9		85	85	85
—14.5°		American	7 x 6	15		80	80	80
			3 x 2	27		90	90	90

TABLE 1 (*continued*)

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
						Cambium	Phloëm	Cortex
—14.5° (*conc.*)	February to March (*concluded*)	1-year French	8 x 7	2	1	100	100	75
			3 x 2	6	....	100	100	100
—9°	March 29 to April 15	1-year French	8 x 6	2	1	....	60	......
			6 x 4	3	3	....	....	......
		American	8 x 6	8	8	....	....	......
			6 x 4	4	2	25	....	.....
		1-year French, stored	8 x 6	3	....	100	100	100
—10°		1-year French	8 x 6	4	....	....	....	......
			6 x 4	4	3	100	45	45
			5 x 3	4	....	60	60	60
		American	8 x 6	5	5	....	....	.....
		1-year French, stored	8 x 6	5	1	100	100	100
—11°		1-year French	8 x 6	2	2	....	....	......
			3 x 2	6	....	100	100	100
		American	8 x 6	5	1	75	....	.....
			6 x 5	4	....	100	100	100
		1-year French, stored	8 x 6	2	....	100	100	100
—12°		1-year French	8 x 6	3	2	100	100	50
			3 x 2	12	. ...	100	100	100
		American	7 x 5	8	.. ..	100	100	100
		1-year French, stored	8 x 6	3	....	100	100	100

TABLE 1 (*concluded*)

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
						Cambium	Phloëm	Cortex
—7°	April 16 to May 8	1-year French	8 x 6	2	2	....	....	.....
			3 x 2	5	....	50	50	50
		American	8 x 6	7	1	100	100	90
			6 x 4	4	.....	....	....	......
		1-year French, stored	7 x 5	2	2	....	....	......
			3 x 2	4	4	....	....	......
—8°		1-year French, stored	7 x 6	4	4	....	....	......
			3 x 2	13	4	80	25	25
		American	8 x 6	4	1	80	25	25
			6 x 4	5	....	90	80	80
		1-year French, stored	8 x 6	2	....	10	....	.....
			6 x 5	2	....	90	90	90
—9°		1-year French	8 x 6	2	2	....	....	......
			3 x 2	7	7	....	....	....
		American	8 x 6	6	3	25	....	....
		1-year French, stored	7 x 4	2	2	....	....	......
			3 x 2	4	....	100	100	100
—10°		American	8 x 6	6	....	70	60	60
			6 x 5	6	....	100	100	100

It is a common opinion among some nurserymen that the French-grown apple stocks are hardier than the home-grown seedlings. The results obtained from the freezing of hundreds of roots of each stock indicate that these differences in resistance are negligible. Both stocks are found to show considerable injury from –11° to –11.5° C., and at –12° few of either sort survived. The two-year French roots were grown

under unfavorable conditions in the nursery, and apparently because of this were more easily killed than the one-year stock. The one-year seedlings held in cold storage for one year showed about the same hardiness as the two-year roots.

The observations of Chandler (1913) led him to conclude that the hardiness of the root tissues varies with the season. This is to be expected and the results obtained readily support this theory. The material frozen in October and November shows a marked tenderness compared with roots tested in February and March. The period of maximum resistance seems to end somewhat before the last of March, tho the date would, of course, vary with the conditions affecting after-ripening and possibly also with the variety. From the first of April until these observations ceased, an increasing amount of injury was noted. This range of hardiness indicates a difference in resistance of between three and four centigrade degrees. These seasonal differences obtain, not only in the apple seedlings, but in all the roots reported in this paper.

The influence of the size of the root in withstanding cold seems reasonably well established by the data in table 1 as well as by those in the succeeding tables. The resistance is in direct proportion to the diameter of the root. In practically all cases in which the whole forked roots of the French seedling were employed, the small roots killed first. Similarly, the smaller roots of the American stocks having the same soil depth suffered more quickly and severely than the larger roots.

The results in the apple tests seem to point rather clearly to the relative resistance of the different tissues in these roots. It is seen, in practically all instances in which injury occurs, that the cambium is the first tissue to be killed. This is followed closely by the phloëm, while the cortex seems somewhat hardier than either of the other tissues. Only a few cases are recorded in which the cortex alone was severely injured, tho frequently the three tissues were equally affected. Unless the temperature is especially low for apple roots, or they are especially tender as in the fall and the spring, the cambium, the phloëm, and the cortex are browned without further injury. Occasionally under extreme conditions the xylem and the pith may be killed, in which case they both seem to show about equal resistance. An exposure at –20° C. would ordinarily kill all the cells in the roots of any apple seedlings tested in these experiments, even when they were in a dormant condition.

A number of observations were made on material four inches long, in which two inches of the plant represented the stem above the soil level and two inches represented the root below the surface of the ground. From the results of these freezings some indications were given as to just where the tenderness of the root tissues ended and the well-known hardiness of the stem tissues began. Where injury occurred to the specimen, the region of browning much oftener than otherwise extended from the lower end of the root upward, decreasing abruptly at the crown. This is somewhere near the point of differentiation of root and stem structures. It was indicated from these data that this difference in resistance may have been brought about by a change in cellular structure.

While Chandler (1913) seemed to find that roots deeper down in the soil were tenderer than those near the surface, an examination of his data shows that the deeper roots were also considerably the smaller in diameter. Many observations of roots of equal transverse section and growing at different soil levels were recorded from time to time. From the results of these observations, it was suggested that the size of the root was, perhaps, a greater factor in its resistance than the soil depth at which it grew.

From the foregoing considerations it is rather difficult to assign a fixed temperature at which an apple-seedling root may be partially or completely injured by freezing. Examination of all of the material tested showed that, while severe injury is found at exposures ranging from –7° to –13° C., one French root survived a temperature of –14.5°. However, the majority of the dormant roots were seriously injured in the three outer tissues by a temperature of –12° C.

RESISTANCE OF PEAR ROOTS TO LOW TEMPERATURE

In the work with pear roots the comparative tenderness of two-year French stock (*Pyrus communis*) and one-year Kieffer stock was determined. The two-year roots were given the same field treatment the second year as was given to the two-year French apples previously mentioned. A few one-year French stocks were also available in 1916.

In almost all cases, as shown by the data recorded in table 2, the one-year Kieffer roots proved more resistant than either of the French stocks. At an exposure of –10° C. in the January-March period, the Kieffer roots show a less number and percentage affected than do the two-year French

roots. The temperature of –11° during dormancy was too low for the survival of either species. In the April tests at –8° the Kieffer stock again demonstrates its superiority. When exposed to –9° in April the Kieffer shows only a small amount of injury in the phloëm while the two-year French roots were killed thruout.

TABLE 2. EFFECT OF LOW TEMPERATURE ON ROOTS OF PEAR SEEDLINGS

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
						Cambium	Phloëm	Cortex
—7°	October 24 to December 15	2-year French	7 x 6 4 x 3	8 5	6 .	20 100	 100	 100
—8°			8 x 6 5 x 3	10 5	2 . . .	75 100	75 100	75 100
—9°			7 x 5 5 x 3	3 6	1 . . .	50 100	50 100	50 100
—10°			9 x 8 4 x 3	3 6	.	60 100	60 100	60 100
—9°	January to March	2-year French	8 x 6 5 x 3	5 8	4 . .	100 100	100 100	100 100
—10°			9 x 7 5 x 4	4 13	1 . . .	100 100	100 100	100 100
		1-year Kieffer	6 x 6	6	3	60	40	40
—11°		2-year French	9 x 7 6 x 4	5 7	1	80 85	85 80	85 80
		1-year Kieffer	7 x 6	7	. . .	100	100	100
—12°		2-year French	7 x 6	4	. .	100	100	100
		1-year Kieffer	8 x 7 7 x 6	2 2	. . . . .	100 10	100 45	100 45
—7°	April 1 to 21	2-year French	8 x 6 4 x 3	2 4	2 3	 50	 50	 50

TABLE 2 (*concluded*)

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
						Cambium	Phloëm	Cortex
—7° (*conc.*)	April 1 to 21 (*concluded*)	1-year Kieffer	6 x 6 6 x 3	3 3	3	 25	....	 100
—8°		2-year French	8 x 5	3	....	100	100	100
		1-year Kieffer	6 x 6	9	7	100	100	100
		1-year French	6 x 6 5 x 4 4 x 3	2 12 8	2 4	.... 60 70	.... 60 70	..... 60 70
—9°		2-year French	7 x 5	3	....	100	100	100
		1-year Kieffer	7 x 5	3	....	0	15	0
		1-year French	6 x 4 3 x 2	9 7	....	75 100	75 100	75 100
—10°		2-year French	10 x 6	3	....	100	100	100
		1-year Kieffer	7 x 6	3	....	100	100	100
		1-year French	8 x 5	3	....	100	100	100

The pear roots, like those of the apple, showed individual variations — an increase in hardiness with an increase in diameter, a region at the crown less tender than the root below, little influence due to depth below the soil surface, relative tenderness of the same tissues, and a gradual acquiring of hardiness thru the winter, reaching the maximum in February and March. This seasonal hardiness, however, seems rather more delayed in the pear root than in the apple.

If the resistance of the pear and the apple seedlings is contrasted, it is found that an approximate difference of from one to two degrees generally obtains, and sometimes even a much greater difference. Thus, while in March the apple does not begin to show much injury until a temperature of −11° or −12° C. is reached, −10° or −11° is sufficient to kill most of the tissues, except the xylem and the pith, in both the French and the Kieffer pear stocks.

RESISTANCE OF ELBERTA PEACH ROOTS TO LOW TEMPERATURE

The name *Elberta* as used here refers only to the bearing surface of the tree and has no reference to the origin of the roots. The peach stocks probably were derived from several different varieties; at least, the range of variation presented in table 3 indicates such a possibility.

TABLE 3. EFFECT OF LOW TEMPERATURE ON ROOTS OF ELBERTA PEACH TREES

Temperature (centigrade)	Date of freezing	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots			
					Cambium	Phloëm	Cortex	Pith
—8.5°	February 12 to March 24	12 x 6	2	2	.....	.....	.....	.....
		5 x 4	4	.....	.....	.....	15	.....
—10°		15 x 8	3	.....	100	100	100	100
		10 x 6	6	2	90	90	90	60
		7 x 5	5	.....	100	100	100	55
		5 x 4	7		65	65	65	45
—11°		15 x 8	1	.....	100	100	100	.....
		10 x 9	5	.....	30	30	35	45
		7 x 5	4	2	.....	.....	.....	100
		5 x 4	7	.....	35	35	35	100
—12°		12 x 8	5	.....	60	60	60	100
		10 x 6	5	.....	40	40	40	100
		7 x 5	3	.....	.....	.....	40	100
		4 x 3	4	.....	50	50	50	100
—14.5°		7 x 6	5	1	65	65	65	100
		7 x 5	5	1	25	25	35	100

TABLE 3 (*concluded*)

Temperature (centigrade)	Date of freezing	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots			
					Cambium	Phloëm	Cortex	Pith
—5 5°	March 25 to April 25	7 x 5	7	3	.....	25	25	......
—7°		11 x 10	3	2	....	100	100	.....
		7 x 5	6	2	20	20	20	.....
—8°		12 x 6	2	....	....	10	25	......
		7 x 5	2	1	....	60	60	......
		5 x 4	4	....	100	100	100	100
—9°		10 x 6	3	....	100	....	100	......
—10°		11 x 10	3	....	100	100	100	. 80
—11°		7 x 5	3	....	100	100	100	75

During the middle of February an exposure at −10° C., included in the February–March period, shows an average injury of 75 per cent in all tissues except the xylem in nineteen out of twenty-one roots. The tests at −11°, which were made on March 1, indicate an average injury of less than 50 per cent. An average injury of from 55 to 60 per cent in all the cells is seen at a temperature of −12°, altho at two and one-half degrees lower two roots out of ten were uninjured.

As a general rule the order of resistance of the various tissues in the peach root seems to be as follows: pith, cortex, phloëm, cambium, xylem. At −18° C. or below, the xylem was usually killed during the hardiest period. In most cases during February and March the pith is the tissue most easily killed, but in April the cambium is the least resistant.

It is not so easy, with the data at hand, to assign an arbitrary limit within which the peach root is injured by freezing. This is because of the great variation in the root tissues. The peach cambium certainly is as hardy as the pear cambium, tho less so than the apple. Regardless of the size of the root, most of the peach material tested showed some injury

at –10° C., and, except in unusual cases, serious injury occurred at –11°. This would then place the hardiness of the peach root very close to that of either pear seedling.

COMPARATIVE RESISTANCE OF MAZZARD AND MAHALEB CHERRY ROOTS TO LOW TEMPERATURE

In the cherry freezing determinations previous to January, 1916, only two-year cherry seedlings were used. Subsequent to that date, only one-year material was tested. A few roots of *Prunus Besseyi* were available in March.

TABLE 4. EFFECT OF LOW TEMPERATURE ON MAZZARD AND MAHALEB CHERRY ROOTS

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots: Cambium	Phloem	Cortex	Pith	Xylem
—7°	October 24 to December 11	Mahaleb	7 x 3 5 x 4	5 5	5 4	... 25	... . . .	. .	.	. ...
		Mazzard	8 x 3 7 x 5	2 2	. ...	50 50	50 50	50 50	. . .	.. . ...
—8°		Mahaleb	10 x 8 9 x 7 5 x 4 4 x 2	2 3 5 5	2 1 3	... 25 15 50	.... 25 60	.... 25 . . . 60	.. . .	... .
		Mazzard	9 x 5 5 x 3	1 4	1	 80	 80	 80	.. ..	. . . .
—9°		Mahaleb	6 x 5 5 x 3	10 2	4 1	50 50	....	....	. . . ..	....
		Mazzard	6 x 5	4	.	80	80	80	... .	.... .
—10°		Mahaleb	10 x 5 5 x 2	2 2	1 . ..	 100	.... 50 100	.. 100	. .	....
—12°		Mahaleb	15 x 13	2	. . .	100	100	100		...
—9°	January 1 to March 29	Mahaleb	7 x 5	2	2	.. .	.	.. .	.	...
		Mazzard	6 x 6 5 x 4	2 3	2 . .	 45	 45	 45	. .	... ...
—10°		Mahaleb	6 x 2	2	2	....	... ..	. .		...
		Mazzard	7 x 6 4 x 2	2 2	. ...	30 .	30 . .	30 . .	. .	... ...
—11°		Mahaleb	7 x 5 4 x 2	6 2	6 . ..	50	 50	. . 50	.	... ...
		Mazzard	8 x 8 5 x 4	6 4	.. ..	85 100	85 100	85 100	. . ..	... ...

TABLE 4 (*concluded*)

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots				
						Cambium	Phloëm	Cortex	Pith	Xylem
—11° (*conc.*)	January 1 to March 29 (*concluded*)	Prunus Besseyi	9 x 7 6 x 3	2 4	....	100 100	100 100	100 100	....	....
—12°		Mahaleb	7 x 6 6 x 3	3 2	2	10 100	10 100	10 100	....	....
		Mazzard	7 x 6	4	....	100	100	100	....	. ...
		Prunus Besseyi	7 x 8 7 x 6	2 2	....	50 100	....	25 30	 100	....
—15°		Mahaleb	10 x 8 7 x 6	7 2	 1	20 30	20 30	20 30	....	....
		Mazzard	10 x 8	7		100	100	100	.	
		Prunus Besseyi	7 x 7	2	....	100	100	100	......	......
—17°		Mahaleb	8 x 7	2	....	75	75	75	......	......
		Mazzard	8 x 7	2	..	100	100	100	100	.....
		Prunus Besseyi	9 x 7	4	....	100	100	100	100	50
—7°	March 30 to April 20	Mahaleb	9 x 4	2	2	......	....	......	......	......
		Mazzard	9 x 8	4	....	100	100	100	......	......
—8°		Mahaleb	8 x 5	4	4	......	....	......	......	......
		Mazzard	12 x 11 8 x 6	2 2	1	40 100	40 100	40 100	....	....
—9°		Mahaleb	9 x 5 8 x 3	2 5	2 4	 15	 15	 15	....	....
		Mazzard	10 x 8 8 x 5	5 5	....	100 100	100 100	100 100	....	....
—10°		Mahaleb	7 x 6 5 x 2	5 2	5	 40	 40	 40	....	....
		Mazzard	10 x 9 8 x 8	4 4	....	100 100	100 100	100 100	 100	 50
—11°		Mahaleb	8 x 4	2	2	......	....	......	......	......
		Mazzard	8 x 8	3	....	100	100	100	100	......
—12°		Mahaleb	9 x 6 7 x 4	2 3	....	60 5	75	75 10	....	....
		Mazzard	12 x 10 8 x 7 7 x 4	2 4 3	....	100 100 100	100 100 100	100 100 100	100 100 100	... .. 100 100

The most striking fact brought out by the data in table 4 is the uniform tenderness of the Mazzard as compared with the Mahaleb stock. This difference can readily be seen in any comparable instance. It extends thru all stages of maturity. Thus, during November, Mazzard tissue was injured much more severely when exposed to –8° C. than was corresponding Mahaleb stock tested at –9°. In the January–March period a similar difference is noted; the six larger Mazzard stocks given an exposure at –11° show 85 per cent browning in the three outer tissues, while three smaller Mahaleb roots were similarly affected only 10 per cent when exposed at –12°. At –15° the Mahaleb tissue suffers relatively little injury, but the two roots subjected to –17° are mostly killed. In the March–April period the continued resistance of the Mahaleb tissue is striking. On April 15 it is about three or four degrees hardier than the Mazzard, which when exposed to –10° is seriously injured in the pith and the xylem. These results are in accord with the field observations of Craig (1900) and the laboratory studies of Chandler (1913).

The freezing tests with *Prunus Besseyi*, altho this is a plum species, are included in the cherry data since it is frequently used as a cherry stock. These results with *Prunus Besseyi* do not bear out the experience of most writers regarding its exceptional hardiness. During the January–March exposures, it is noted that at –11° C. this variety was injured somewhat more than was the Mazzard. At –12° it was rather more resistant than the Mazzard but the pith in the smaller roots was killed thruout. At –15° and –17° it suffered equally with the Mazzard or worse.

Under field conditions with severe freezing, Craig (1900) found *Prunus Besseyi* much hardier than all other stocks used for cherries. The writer is not prepared to say that the hardiness of this species has been overestimated. His own very limited experience, however, shows it to be inferior in resistance to Mahaleb, and slightly better than Mazzard. Since the writer is not familiar with the *Prunus Besseyi* stock, it is of course possible that the roots tested as recorded above were not of this species. The only evidence that they were correctly named is from the nurseryman who sold them as such.

A small amount of data on *Prunus avium* and *Prunus pennsylvanicum*, not included in table 4, indicate merely that these roots seem to be quite as easily killed by freezing as are Mazzard roots. Since these roots were taken directly from the partly frozen ground in April, they were rather

moist and were probably beginning activity. A larger number of determinations under different conditions might entirely change the tendency just mentioned.

Considering the data on the four cherry stocks, their order of relative hardiness seems about as follows: Mahaleb, *Prunus Besseyi*, *Prunus pennsylvanicum*, Mazzard. If the Mahaleb cherry is compared with the apple, it is seen that the resistance of the former is markedly superior in most cases. In large Mahaleb roots during their hardiest period, little injury is found under –14° C., while at –15° the injury is relatively small. *Prunus Besseyi* did not survive a temperature of –11°. *Prunus pennsylvanicum* succumbed at –10° or –11°, altho the date of freezing may partly account for its tenderness. The Mazzard roots in no instance withstood –11°, but the number of tests run at –10° was insufficient to place this as its minimum. From these results the Mazzard cherry stock does not appear hardier than Kieffer pear stock.

RESISTANCE OF MYROBALAN PLUM ROOTS TO LOW TEMPERATURE

Unfortunately, only one commonly used plum stock was available in this work, aside from the *Prunus Besseyi* roots included in table 4 with the cherry stocks. The number of one-year Myrobalan roots tested was too small to give very conclusive results. However, some indication at least of its comparative hardiness may be gained from table 5. The data in this table place the one-year Myrobalan root in the same group in regard to hardiness as the pear and the Mazzard cherry. The Myrobalan plum does not appear quite so hardy as the Kieffer pear and probably it would prove to be less hardy than a vigorous one-year French pear. The fact that the roots of the latter are normally somewhat larger than the average plum roots, would give still more evidence in favor of the superior hardiness of the pear.

TABLE 5. EFFECT OF LOW TEMPERATURE ON MYROBALAN PLUM ROOTS

Temperature (centigrade)	Date of freezing	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
					Cambium	Phloëm	Cortex
—7°	October 24 to December 20	8 x 7 5 x 3	2 5	....	50 65	50 65	10 65
—8°		5 x 4	3	. . .	100	100	100
—9°		7 x 5 5 x 3	3 2	1 . .	100 100	100 100	100 100
—10°		9 x 5 8 x 7	2 2	. . . . . .	80 65	80 65	80 65
—9°	January 1 to March 29	7 x 6 5 x 4 2 x 1	6 11 11	. . . .	100 30 40	100 30 40	100 35 40
—10°		8 x 5 5 x 4	2 9	. . . .	100 80	100 80	100 80
—11°		9 x 7 5 x 4	2 4	. . .	75 100	75 100	75 100
—8°	April 1 to 8	6 x 5 5 x 4 3 x 2	5 7 13	. . . .	80 25 80	80 25 80	80 60 100

RESISTANCE OF THE ROOTS OF SIX GRAPE VARIETIES TO LOW TEMPERATURE

It is well known that there is a rather wide difference in hardiness in the canes of certain varieties of grapes. Such a variation, tho less important and conspicuous, is found also in grape roots. To determine these differences, six varieties were selected for testing, embracing several species.

According to Hedrick (1908), the varieties used represent the following species: Concord, *Vitis labrusca*; Clinton, *Vitis vulpina* and *Vitis labrusca*, the variety being more characteristic of the former species; Diamond, *Vitis labrusca* and *Vitis vinifera*, the former predominating; Lindley, *Vitis labrusca* and *Vitis vinifera*; Norton, *Vitis aestivalis* and *Vitis labrusca*,

the variety being mostly derived from the former species; Cynthiana, *Vitis aestivalis* and *Vitis labrusca*, the former predominating. All of the roots tested were from healthy, one-year plants. Since none of the roots were large in diameter, a greater number could be tested in a single freezing than is possible with most material; also, the uniformity in size excluded variations due to differences in diameter.

The results given in table 6 show clearly that these varieties readily divide themselves into two classes: one in which the tissues are rather resistant to cold, and another in which the roots are relatively easy to kill by freezing. Clinton, Concord, and Diamond belong in the first group; Cynthiana, Lindley, and Norton fall into the second group.

TABLE 6. EFFECT OF LOW TEMPERATURE ON THE ROOTS OF SIX GRAPE VARIETIES

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots				
						Cambium	Phloëm	Cortex	Pith	Xylem
—9°	February 1 to March 17	Lindley	3 x 2	11	**11**	......	......	......	......	......
		Cynthiana	3 x 2	10	**10**	......	......	......	......	......
		Diamond	3 x 2	9	**9**	......	......	......	......	......
		Concord	2 x 2	8	**8**	......	......	......	......	......
—10°		Lindley	3 x 2	10	**10**	......	......	......	......	......
			3 x 1	22	....	60	60	60	......	......
		Cynthiana	4 x 3	10	....	75	75	75	......	......
		Diamond	3 x 1	13	**10**	60	60	60	......	......
		Concord	3 x 2	12	**12**	......	......	......	......	......
		Clinton	3 x 2	15	**15**	......	......	......	......	......
—11°		Lindley	3 x 2	12	**2**	60	40	30	......	......
			3 x 1	18	**1**	100	100	100	......	......
		Cynthiana	3 x 2	20	**5**	55	55	55	......	......
			2 x 1	15	....	100	100	100	5	10
		Norton	3 x 2	23	**3**	60	60	60	......	......
			2 x 1	18	**3**	100	100	100	......	......
		Diamond	3 x 2	21	**17**	35	......	......	......	......
			2 x 1	11	**11**	......	......	......	......	......
		Concord	3 x 2	11	**6**	25	25	25	......	......
			2 x 1	71	**54**	45	45	45	......	......
		Clinton	3 x 2	30	**30**		......	......	......	......
			2 x 1	6	**6**	......	......	......	......	......
—12°		Lindley	3 x 2	25	....	100	100	100	......	10
		Cynthiana	4 x 1	14	....	100	100	100	10	......
		Norton	4 x 1	18	**5**	60	60	60	......	10
		Diamond	3 x 1	15	**12**	20	20	20	......	......
		Concord	3 x 1	15	**13**	5	5	5	......	......
		Clinton	3 x 1	18	**18**	......	......	......	......	......
—13°		Cynthiana	3 x 2	8	....	100	100	100	......	......
		Norton	3 x 2	16	....	100	100	100	......	......
		Diamond	3 x 2	18	**18**	......	......	......	......	......
		Concord	3 x 2	20	**20**	......	......	......	......	......
		Clinton	3 x 2	20	**18**	10	......	......	......	......

TABLE 6 (*concluded*)

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	**Number of roots uninjured**	Per cent of cells killed in injured roots				
						Cambium	Phloem	Cortex	Pith	Xylem
—14.5°	February 1 to March 17 (*concluded*)	Lindley	3 x 2	18	......	100	100	100	40	50
		Cynthiana	3 x 2	8	......	100	100	100	25	30
		Norton	3 x 2	18	......	100	100	100	40	30
		Diamond	3 x 2	27	**9**	60	50	60	......	......
		Concord	3 x 2	27	**22**	2	......	2	......	......
		Clinton	3 x 2	16	**8**	90	90	90	......	......
—15.5°		Diamond	3 x 2	15	**10**	35	35	35	......	......
		Concord	3 x 2	15	**10**	20	20	20	......	......
		Clinton	3 x 2	15	**10**	35	35	35	......	......
—18°		Diamond	3 x 2	12	......	100	100	100	......	40
		Concord	3 x 2	12	......	100	100	100	......	20
		Clinton	3 x 2	12	......	100	100	100	......	......
—8°	March 21 to April 17	Lindley	3 x 2	17	**12**	20	20	20	......	......
		Cynthiana	3 x 2	8	**6**	20	......	......	......	......
		Norton	3 x 1	8	**5**	......	100	100	......	......
—9°		Lindley	4 x 3	9	**4**	15	15	25	......	......
		Cynthiana	3 x 2	8	**2**	65	65	55	......	......
		Concord	3 x 2	11	**6**	30	......	......	......	......
—10°		Lindley	3 x 2	17	......	100	90	90	10	10
		Cynthiana	3 x 2	18	**5**	55	50	55	......	......
		Concord	3 x 2	8	......	10	10	10	......	......
		Clinton	3 x 2	6	**5**	10	10	10	......	......
—11°		Lindley	3 x 2	30	......	65	65	65	......	......
		Cynthiana	3 x 2	24	**1**	90	90	90	......	25
		Norton	3 x 2	6	......	100	100	100	......	50
		Diamond	3 x 2	8	......	100	100	100	......	......
		Concord	3 x 2	13	**5**	65	65	65	......	......
—12°		Lindley	3 x 2	26	......	100	100	100	90	90
		Cynthiana	3 x 2	12	......	100	100	100	75	50
		Norton	3 x 2	31	......	100	100	100	90	85
		Diamond	3 x 2	18	**3**	100	100	100	......	15
		Concord	3 x 2	23	**5**	100	100	100	50	15
		Clinton	3 x 2	20	**2**	100	100	100	50	50
—14.5°		Lindley	3 x 2	12	......	100	100	100	100	85
		Cynthiana	3 x 2	12	......	100	100	100	100	75
		Norton	3 x 2	12	......	100	100	100	100	60
		Diamond	3 x 2	12		100	100	100	100	75
		Clinton	3 x 2	12	......	100	100	100	100	5

Careful comparison of Clinton, Concord, and Diamond during two seasons showed that in 1916 Clinton proved slightly the hardiest, Concord was second, and Diamond was the tenderest of the three. In 1917 Diamond still ranked third, but Clinton and Concord exchanged places. However, the differences in either case were always very small and were probably due to inherent variation. On examination of the determinations made previous to March 17 (table 6), the limits of this hardier group are appar-

ent. Only scattering injury is recorded at $-11°$, $-12°$, and $-13°$ C. At an exposure of $-14.5°$, twenty-two out of twenty-seven Concord roots were uninjured and only a trace of cambium and cortex injury was noted in the remainder. One-half of the Clinton and two-thirds of the Diamond roots were injured more than 50 per cent by the same temperature. At $-15.5°$ an injury of 20 per cent is seen in one-third of the Concord roots and 15 per cent more in the other two varieties. At $-18°$, however, the cambium, phloëm, and cortex tissues were completely injured in all roots, with some xylem injury in the Diamond and the Concord. By March 21 tenderness began to return, and a few days later these varieties were severely injured by temperatures several degrees higher.

A contrast of the root resistance in the varieties of the second class shows the following order of hardiness: Norton, Lindley, Cynthiana. The variations, however, are so slight that they may be entirely disregarded.

In 1917 Cynthiana was quite as resistant as Norton, as shown by the injury in both at the higher and lower temperatures. Lindley seemed to be a trifle easier to kill than either Cynthiana or Norton in 1916, but here again the differences are slight. The limits of this second group as shown in table 6 lie between $-10°$ and $-12°$ C., the roots usually undergoing considerable injury at $-11°$. In relative hardiness this places these varieties between the Mazzard cherry and the apple.

The Clinton, Concord, and Diamond roots, even excluding the influence of size, are considerably more resistant than apple roots, and Concord and Clinton seem equal if not superior to the Mahaleb stock.

The results shown on comparing the hardiness of the respective species of grapes are somewhat as would be expected. *Vitis aestivalis*, represented by Norton and Cynthiana, is not adapted to severe cold, and this may account for the fact that its range is limited to the South. The tenderness of Lindley is probably due in part to the influence of *Vitis vinifera*, which, as is well known, will not survive the winter in the latitude of New York State without much protection. Concord and Diamond represent *Vitis labrusca*, the Northern Fox grape, which, while restricted in distribution, is found in Maine. *Vitis vulpina*, represented by Clinton — a variety with extremely resistant roots — has the greatest range of any American species of grape, it having been found in Canada north of Quebec.

RESISTANCE OF BLACKBERRY, DEWBERRY, AND RED RASPBERRY ROOTS TO LOW TEMPERATURE

An attempt was made to test representative varieties of blackberries, dewberries, and red raspberries, in order to determine any varietal or specific differences in the hardiness of their roots. But, since many of the roots either were dead when received or blackened soon afterward, little variation among varieties is recorded. Only one-year plants were used. Since the one-year roots of the black raspberry are so small, and injury to them is difficult to detect, no data are given on this species.

Comparison of the resistance of the blackberry varieties recorded in table 7 shows the Eldorado to be apparently the least affected. The roots of the Early Harvest and the Watt show about equal tenderness.

TABLE 7. EFFECT OF LOW TEMPERATURE ON THE ROOTS OF BLACKBERRY, DEWBERRY, AND RED RASPBERRY

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots				
						Cambium	Phloem	Cortex	Pith	Xylem
—9°	March 6 to 20	Eldorado	5 x 4	5	5	...	...	...	...	...
		Watt	5 x 4	5	1	50	50	50	...	...
		Early	6 x 5	2	2	...	...	...	...	...
		Harvest	5 x 4	3	...	45	45	45	...	...
		Lucretia	4 x 3	5	5	...	...	...	...	...
		Austin	5 x 4	5	2	85	85	85	...	...
—10°		Eldorado	3 x 2	10	10	...	...	...	...	...
		Watt	3 x 2	7	...	60	60	60	40	...
		Early Harvest	3 x 2	11	9	50	50	50	50	
		Lucretia	3 x 2	10	9	25	25	25	...	...
		Austin	3 x 2	10	9	25	25	25	...	...
—11°		Eldorado	5 x 4	6	4	15	15	15	...	...
		Watt	5 x 4	7	5	100	100	100	50	...
		Early Harvest	5 x 4	6	5	100	100	100	...	...
		Lucretia	5 x 4	5	4	50	50	50	...	...
			3 x 2	8	3	100	100	100	...	...
—12°		Eldorado	6 x 5	12	...	100	100	100	20	.
		Watt	6 x 5	10	...	100	100	100	20	
		Early Harvest	5 x 5	5	...	100	100	100	35	...
		Lucretia	5 x 4	8	1	75	75	75	...	...
		Cuthbert	4 x 4	6	...	100	100	100	100	...
—7°	March 23 to April 17	Eldorado	6 x 5	2	1	...	...	...	10	.
			3 x 2	11	11	...	...	...	...	...
		Watt	3 x 2	7	7	...	...	...	...	...
		Early Harvest	3 x 2	7	7	...	...	...	...	...
		Lucretia	2 x 1	17	15	...	...	25	...	...
		Austin	2 x 1	11	11	...	...	...	...	...

TABLE 7 (*concluded*)

Temperature (centigrade)	Date of freezing	Variety	Diameter of roots (millimeters)	Number of roots	**Number of roots uninjured**	Per cent of cells killed in injured roots: Cambium	Phloem	Cortex	Pith	Xylem
—7° (*conc.*)	March 23 to April 17 (*concluded*)	Cuthbert	4 x 3	6	**6**	....	....	......	......	......
		Perfection	3 x 2	10	....	....	....	....	......	......
		Loudon	4 x 3	5	**4**	....	....	10	......	......
			3 x 2	4	**2**	......	....	25	......	......
—8°		Eldorado	7 x 2	4	**4**	......	....	......	......	......
		Watt	3 x 2	7	**7**	......	....	......	......	......
		Early Harvest	3 x 2	6	**6**	......	....	......	......	......
		Lucretia	5 x 5	3	**3**	......	....	......	......	......
			3 x 2	20	**14**	50	50	50	......	......
		Cuthbert	7 x 5	3	**3**	......	....	......	......	......
			3 x 2	3	....	......	....	100	......	......
		Perfection	5 x 3	5	**3**	......	....	100	......	......
		Loudon	6 x 4	4	**4**	......	....	......	......	......
			4 x 2	4	....	......	....	50	......	......
—9°		Eldorado	8 x 8	3	**1**	70	20	20	50	......
			5 x 5	8	....	60	60	60	30	35
		Lucretia	4 x 3	10	**9**	25	25	25	......	......
			3 x 2	4	**2**	20	20	20	......	......
		Cuthbert	5 x 5	4	**2**	100	100	100	......	......
			3 x 2	3	....	......	....	100	......	......
		Perfection	3 x 2	4	**3**	90	90	90	......	......
—10°		Eldorado	6 x 5	9	**1**	95	100	95	100	60
		Lucretia	3 x 2	8	**2**	55	55	55	......	......
		Cuthbert	5 x 4	6	....	100	100	100	......	......
		Perfection	3 x 2	10	....	100	100	100	......	......
—11°		Eldorado	6 x 5	10	....	100	100	100	50	50
			7 x 2	2	....	75	75	75	60	......
		Watt	5 x 4	3	....	100	100	100	100	80
		Lucretia	5 x 4	6	**1**	90	90	90	75	75
		Cuthbert	5 x 3	9	....	100	100	100	......	......
		Perfection	5 x 4	7	....	100	100	100	......	......
—12°		Eldorado	5 x 4	5	....	100	100	100	100	100

At an exposure of −9° C., three roots out of five of the Austin dewberry were killed while the Lucretia was unhurt. In practically all comparable freezings, the Lucretia seems a trifle hardier than the Eldorado blackberry, but the margin of difference is small.

A comparison of the red raspberry varieties indicates the advantage of the Cuthbert root over the Perfection. The number of Loudon roots tested was not sufficient to permit comparison. Contrast of the relative resistance of Cuthbert as compared with Lucretia suggests the superior hardiness of the latter, while Cuthbert has the approximate killing point of the Eldorado blackberry.

It is seen from the results given in table 7 that none of this Material survived a temperature of –12° C. However, many of the larger roots tested at –11° previous to March 20 were uninjured. Their relative hardiness, therefore, would place these varieties in the group with the Myrobalan plum and the Mazzard cherry.

RESISTANCE OF GOOSEBERRY AND CURRANT ROOTS TO LOW TEMPERATURE

The study of the freezing point of gooseberry and currant roots offered more difficulty than any other determinations undertaken. During the winter of 1915–16 a large amount of currant and gooseberry material was tested; in fact, in nearly every freezing a few roots of these species were included. Upon examination for injury no appreciable change could be observed within the usual time limit. At the end of a still longer period between the testing and the examination, no features were exhibited that the unfrozen roots did not possess. Owing to the pink or reddish pigment found in the cells of the cortex, these cells were examined for injury under the microscope. At –15° C. no discoloration suggesting injury was noted.

It was accordingly decided to repeat the experiment with the gooseberry and the currant roots in a somewhat different way. The varieties were restricted to the Downing gooseberry and the Wilder currant. In this test, whole two-year plants were root-pruned to about four inches and the tops were cut back to four or five branches with three buds left on each. The plants thus treated were then placed in the freezing chamber. At the same time four-inch pieces of root for microscopic examination were tested. After each determination the plants were immediately placed in moist sawdust in common storage, where they were allowed to remain until May 10. On that date they were planted out in the field.

Observations on these plants were taken on June 16, and record was made of the growth that had taken place up to that time. On August 4, the observations were repeated, and it was found that no growth had taken place in any of the specimens recorded as dead in June. These data serve as criteria for the amount of injury that the roots experienced. It is clear that this method is less exact than the previous manner of determining injury by direct observation. It is not possible, for example, to state the size of root affected, or the tissues and the amount of roots

killed, except as these facts are expressed by the relative top growth. Still this test, supplemented by the microscopic observations, should suggest the approximate and comparative resistance of the two species.

TABLE 8. EFFECT OF LOW TEMPERATURE ON GOOSEBERRY AND CURRANT ROOTS (April 3–11, 1917)

Temperature (centigrade)	Serial number	Variety	Number of roots	Depth in soil (inches)	Diameter of roots (millimeters)	Results
—19°	1	Wilder.....	10	6–8	1–6	5 small leaves present; most of stem seemed alive, but growth seriously if not fatally delayed
	2	Wilder.....	9	8–10	2–6	1 small yellow leaf appeared; most of stem tissues brown
	3	Wilder.....	12	6–10	2–6	No leaves present; stem seemed entirely dead thruout
	4	Downing...	13	8–10	1–6	10 or more small green leaves present; stem tissues seemed active
	5	Wilder.....	9	4–8	3–6	Sections examined, 6 mm. and 3 mm. Less than 5 per cent of cortex cells appeared brown
	6	Downing...	8	4 –8	3–6	Sections examined, 5 mm. and 3 mm. Small root seemed the less affected, but 50 per cent of cortex appeared injured in each
—20.5°	7	Downing...	6	4–8	3–6	Sections examined, 6 mm. and 3 mm. No cambium injury; at least 50 per cent of cortex cells appeared injured, with a brownish yellow color
	8	Downing...	9	5–8	1–6	8 small leaves had developed; slightly more injury than in no. 4
	9	Downing...	9	6–8	1–5	No leaves present; buds and stem seemed entirely dead
—18°	10	Wilder.....	8	8	1–6	No leaves present; entire top dead as in no. 9
	11	Wilder	7	8	1–6	Same condition of top as in no. 9
	12	Wilder.....	8	8	2–6	Same condition of top as in no. 9
—19°	13	Wilder.....	5	4–8	3–6	Sections examined, 5 mm. and 3 mm. Injury less severe than in no. 7 Downing, but on one side of cortex 50 per cent of cells killed, on the other side 30 per cent injured
—17°	14	Downing...	12	10	1–6	40 or more medium-sized green leaves had developed; more vigorous top than any of preceding
	15	Downing...	15	8	1–6	A few less leaves than in no 14, but all stem tissues active
	16	Downing...	15	8	2–6	Practically the same conditions as in no. 15

TABLE 8 (*concluded*)

Temperature (centigrade)	Serial number	Variety	Number of roots	Depth in soil (inches)	Diameter of roots (millimeters)	Results
—17° (*conc.*)	17	Downing.	9	4–8	1–5	Sections examined, 5 mm. and 3 mm. In small root 25 per cent of cortex cells were of a characteristic yellow color; large root appeared with 35–40 per cent injury
	18	Wilder .	10	8–10	2–6	Not a leaf present; bud and stem dead thruout
	19	Wilder. . .	6	10	1–6	Complete injury to top as in no 18
	20	Wilder	9	6–8	2–5	Sections examined, 5 mm. and 3 mm. 85 per cent of cambium, phloëm, and cortex seemed browned in both large and small root; severest injury thus far observed
—18.5°	21	Downing...	12	10	1–6	15 or more small green leaves present; stem tissues seemed active
	22	Downing...	15	8	1–6	No leaves developed; buds and stem entirely brown
	23	Downing...	9	4–8	2–5	Not more than 10 per cent of injury in cortex, with no browning in cambium or phloem cells
	24	Wilder.....	10	10	1–5	No leaves present; top still had considerable live tissue
	25	Wilder.....	10	8	1–6	No leaves developed; buds and stem entirely dead
	26	Wilder.....	8	4–8	2–5	Only 5 per cent of cortex cells seemed injured, with no browning in other tissues
—18°	27	Wilder . ..	18	4–8	1–6	12 leaves present, ranging in size from 1 to 4 cm. wide
	28	Wilder....	14	8	2–6	No leaves developed; whole top completely dead
	29	Wilder....	15	8	2–5	No leaves present; small amount of live cortex and phloem appeared in one stem
	30	Downing..	7	4–8	2–6	25 or more medium-sized leaves; all stem tissues active
	31	Downing .	11	6–9	1–6	A few less leaves present than in no. 30; otherwise the same
—16.5°	32	Wilder.. .	9	4–8	1–5	No leaves developed; top appeared dead thruout
	33	Wilder	13	6–12	1–6	No leaves developed; considerable active stem tissue
	34	Downing ..	11	4–8	1–6	8 leaves present; all stem tissues seemed alive
	35	Downing.	15	4–8	1–6	12 leaves present; no dead tissue in the top

From an examination of numbers 1, 2, 3, and 4 in table 8, the gooseberry seems slightly hardier than the currant. The microscopic examination of numbers 5 and 6, however, are not in accord with the field test. While the roots sectioned were kept for four days under the bell jar before examination, it is possible that the currant, at least in this case, may offer another instance of delayed death after freezing.

In the next test no currants were included. One Downing survived a temperature of –20.5° C. but, since one was killed completely, this minimum would probably be near the limit of the gooseberry's hardiness at this season. However, microscopic observations showed no more cell injury than in material exposed to –19°.

In numbers 10 to 20, considerable evidence is presented to show a greater resistance in the gooseberry root than in the currant. The microscopic examination also bears this out. Further examination of the data from numbers 27 to 35 gives additional proof of the gooseberry's superior hardiness. But in the last determination the increase in tenderness of the gooseberry is noticeable.

One point especially to be remembered in regard to this table is the date of freezing. On comparing the killing temperature of all of the roots in the other species considered, the relative resistance of the currant and the gooseberry, particularly the latter, is very obvious. These differences represent a range of from five to ten centigrade degrees below the killing temperature of the other roots.

SAP CONCENTRATION OF AMERICAN AND FRENCH APPLE SEEDLINGS AND WILDER CURRANT AS MEASURED BY THE FREEZING-POINT DEPRESSION

It was thought possible that the wide variation in hardiness shown by the roots in the preceding experiments might be due in part to differences in the concentration of the cell sap. Consequently an effort was made to ascertain the sap concentration of the various species. Unfortunately, however, in many cases the sap was found to be very difficult to obtain. In the red raspberry, the dewberry, and the grape, respectively, the sap tissue from the roots of twenty-five plants when expressed yielded less than a cubic centimeter of sap. In other cases sufficient material was not available for this determination.

In the few instances reported in table 9, the roots used for each determination were first entirely killed by freezing. The concentration was determined by means of a Beckmann freezing-point apparatus, and the results, expressed as freezing-point depression, are given in table 9:

TABLE 9. SAP CONCENTRATION IN THE ROOTS OF AMERICAN AND FRENCH APPLE SEEDLINGS AND WILDER CURRANT AS MEASURED BY THE FREEZING-POINT DEPRESSION

Date	Variety	Depression
April 25	American apple roots, upper half	2.487
April 25	American apple roots, lower half	2.214
May 12	Wilder currant roots	2 685
May 12	One-year French apple roots stored one year	2 461
May 12	Two-year French apple roots	1 988

The data in table 9 show a considerable difference in depression between the sap of the one- and the two-year-old French apple roots. Indeed, these differences indicate a wider variation than actually existed. The sap concentration of the two parts of the American apple root may partly explain the fact that the upper half of this root usually suffered less injury than did the lower half at the same temperature. A difference in depression of 0.273 should certainly be of some significance. The root of the Wilder currant proved to have the highest concentration of sap of any of the roots tested. It is indeed, the hardiest of these roots. While this superior sap concentration is not without meaning, it probably does not wholly explain the exceptional resistance of this variety to low temperature.

EFFECT OF RAPID TEMPERATURE FALL ON THE FREEZING OF APPLE ROOTS

Pfeffer (1903:235) stated that "resistant plants withstand rapid and slow cooling equally well, and it is doubtful whether a rapid fall of temperature is more injurious to plants killed by freezing than is gradual cooling." Winkler (1913), however, working with Pfeffer, found that various buds endure a much lower temperature when the fall is very slow.

Chandler (1913), testing many kinds of fruit buds and twigs, found the rate of freezing to be an important factor in the killing temperature.

He observed further that the injury by quick cooling seemed more serious when the rapid fall took place in the early part of the freezing period. The latter observation is in accord with Müller-Thurgau's (1880 and 1886) determinations from which he calculated the size and the time of formation of ice masses in the apple and the potato.

Mix (1916) found that tissue from the trunks of apples killed at a temperature several degrees higher when rapidly frozen than when frozen more slowly.

Some data were procured in this study with a view of determining just how great a difference in injury there would be between roots cooled rapidly and those cooled slowly. An attempt was made also to find out whether the severer injury came during the early or the late period of freezing.

In one freezing the temperature of the air surrounding a large number of roots, all but a few of which were American-grown apple seedlings, was lowered from 1.5° to –4° C. in one hour and forty minutes, and from –4° to –8° in twenty minutes, when the roots were removed. In another freezing the temperature with the same kind of roots was lowered from 1.5° to –4° in twenty minutes, and from –4° to –8° in one hour and twenty-five minutes, when the roots were removed. It is difficult to draw conclusions from but one freezing of each kind, and therefore the data are not included. In the second freezing in which the rapid temperature fall was at the beginning — that is, from 1.5° to –4° C.— the killing was slightly the worse, tho a few French seedlings included were not killed as badly as in the first freezing.

Of course it should be borne in mind that the roots in the second freezing probably reached a lower temperature than did those in the first. It is doubtful whether the roots themselves actually reached the temperature of –8° C. in twenty minutes. The results suggest that there is little difference in the effect on the killing temperature, whether the rapid temperature fall is near the point where freezing begins or nearer the point of the killing temperature. Many more freezings would be necessary, however, before conclusive results could be reached.

Another set of three freezings was made in order to learn the effect of rapid temperature fall on the amount of injury done. In one freezing an attempt was made to approach what would be a normal temperature fall, the temperature falling from 1.5° to –8° C. in three hours and ten minutes.

In the second freezing the temperature fell from 1.5° to -8° in forty-five minutes, when the roots were removed. In the third freezing the temperature fell from 1.5° to -8° in fifteen minutes, and the roots were held at that temperature for one hour. It is of course probable that in the second freezing, in which the roots were removed at once when the temperature of the surrounding air had reached -8° C., the tissue of the roots never reached that temperature. The injury was certainly the least with the slow temperature fall; it was somewhat greater in the second freezing, in which the roots were removed at once; and it was markedly greater in the third freezing, in which, after the temperature had fallen to -8° in fifteen minutes, the roots were held at that temperature for one hour. Thus, with the slow temperature fall, of twelve pieces of American roots seven had no injury, one had 15 per cent of the cambium browned, three had from 30 to 35 per cent of the cambium browned, and one had from 50 to 80 per cent of the cambium browned; in the second freezing, in which the roots were removed immediately after the temperature had reached -8° C. in forty-five minutes, of fourteen pieces of American-grown apple roots five were uninjured, one was very slightly injured, three had from 10 to 20 per cent of the cambium browned, with slight injury to the phloëm and the cortex, one had 25 per cent of injury in these tissues, three had from 50 to 75 per cent of injury, and one was apparently killed thruout; in the case of the third freezing, in which the roots were held at -8° C. for one hour after the surrounding air had dropped to that temperature in fifteen minutes, of nineteen pieces of American-grown apple roots seven showed from 25 to 60 per cent of cambium injury and the remainder showed more injury than that, three being killed practically thruout. Comparing these last two freezings with the slow freezing, it is plain that the rapid temperature fall was the most injurious. In all of these freezings careful records were kept as to the resistance of roots near the surface and of those that had grown deeper in the soil, and roots of the same size showed approximately equal resistance regardless of the soil depth from which they came.

EFFECT OF RATE OF THAWING ON THE FREEZING OF ROOTS

Göppert (1830) concluded, after many experiments, that the rate of thawing had nothing to do with the subsequent injury caused by cold. This view was contrary to the popular belief of his time. Sachs (1860)

stated that "the same tissue which, after exposure to freezing temperature, with slower thawing remained alive unhurt, becomes disorganized when with similar freezing it is thawed rapidly." [3] Müller-Thurgau (1886) pointed out that Sachs' method of placing his tissues in cold water to thaw them was really a case of rapid thawing, since a layer of ice formed about the tissues, thus releasing considerable heat. Müller-Thurgau, using many plants and plant parts, found that the ripe fruits of the pear and the apple, and the leaves of *Agave americana* L., were injured somewhat less when slow thawing was practiced. Molisch (1897) confirmed these results of Müller-Thurgau. Chandler (1913), in his experiments, also found that when the temperature did not go too low, slow thawing reduced the injury to ripe apple and pear fruits and to lettuce leaves; the rate of thawing did not influence the amount of injury to the many other tissues studied.

In this work several experiments were conducted to determine the influence of slow and of rapid thawing on most of the root species used. After being lowered to the killing temperature the material was divided into four comparable lots. It was then thawed at the following temperatures: slightly below freezing but gradually rising; at 0° C.; at 8° C. in the basement storage; and at 22° C. in the laboratory. After a number of hours all the lots were placed under a bell jar at room temperature. Slight differences were noted, but these were confined to very narrow limits and seemed to result from an inherent tendency to vary rather than to be due to any particular set of thawing conditions. When summarized the variations practically canceled themselves and no specific effect could be attributed to the rate of thawing.

INJURY TO APPLE ROOTS WHEN FROZEN IN SOIL, IN WATER, AND IN PARAFFIN

Some determinations were made in which American-grown apple roots were placed in the freezing chamber and completely surrounded by a garden loam soil. In one case the soil was well dried by exposure to warm air. In another case enough water was added to the loam to make it rather muddy. A third soil contained a normal amount of moisture. Twenty-five roots were used in each treatment, and, except in the case of the muddy soil, an effort was made to pack the earth about the roots. In a fourth determination water was substituted for the soil. The water

[3] Translation from the original German.

came well above the top of the material. When the thermometer and the roots were removed after the freezing period, the water was frozen into a solid block of ice about them.

The conditions of these determinations seem too artificial to justify the presentation of tables, but the results may be briefly stated. On comparing the influence of the different soils with a normal air determination, it was found that the roots frozen in air-dried loam were very nearly as resistant to cold as were those frozen in the air. The roots treated in muddy and normal soil seemed slightly easier to injure than those tested in the air or in the air-dried loam. However, these differences were hardly large enough to be dependable, especially when the natural tendency of the species to vary is considered. The material surrounded by water manifested no constant behavior different from that of the other roots.

Since it was believed that the freezing might not be uniform in such a large volume of water, and that severer injury might occur in certain areas of the tissue than in other areas due to the presence of air pockets, another test was made some weeks later. One resistance thermometer was placed in a graduated cylinder of 100 cubic centimeters capacity; a second was placed in water in a large test tube $1\frac{1}{2}$ by 5 inches in size; and a third was exposed to the air in the chamber. Pieces of apple root were placed in large test tubes with and without water. While a large quantity of salt and ice was being used, the readings given in table 10 were recorded. It is evident from this table that low temperature can be temporarily excluded by appropriate quantities of water. After a certain period of time, however, such protection becomes ineffective. The length of time of such insulation seems to vary with the volume of water used.

On examining another large test tube taken from the freezing chamber, in which were placed three medium-sized apple roots, it was noticed that some of the water in the tube was unfrozen. It seems significant also that when the roots were examined two days later, not a cell appeared to be injured, while the cambium, the phloëm, and the cortex tissues of three similar roots placed in the air were entirely dead. The water in the graduated cylinder in which a thermometer was placed was completely frozen.

From these facts the effect of the water seems to be due to the unfrozen water. When the entire mass becomes ice, it readily conducts the heat out of the interior.

TABLE 10. INFLUENCE OF AIR AND WATER IN LOWERING THE TEMPERATURE AROUND RESISTANCE THERMOMETERS

(August 4, 1917)

Hour	Temperature (centigrade)		
	Thermometer in graduated cylinder	Thermometer in large test tube	Thermometer in air
3.00	11°	13°	15°
3.20	4.5°	6°	8°
3.30	0°	4.5°	6.5°
3.45	0°	1°	3°
4.00	0°	0°	—0.5°
4.10	—0.5°	—0.5°	—5.5°
4.20	—0.5°	—0.5°	—9.5°
4.30	—0.5°	—0.5°	—10.5°
4.45	—0.5°	—0.5°	—11°
5.00	—0.5°	—0.5°	—11.5°
5.15	—1°	—0.5°	—11.5°
5.30	—2°	—0.5°	—12°
5.45	—7°	—1°	—12°
6.00	—11.5°	—3°	—12°
6.15	—12°	—8°	—12°

A rather extensive series of seventy-one tests was conducted, to determine whether water or paraffin might be possible factors in influencing the amount of injury. The method and results of these tests were as follows:

Apple roots were placed in ordinary test tubes, which were sealed and in their turn put into larger test tubes, and the surrounding space was filled with water, paraffin, or air. Other apple roots were completely coated with melted paraffin and frozen in the usual way, while still others were immersed and frozen in test tubes containing water. All the lots were given an exposure of from –9° to –12° C.

In most cases in which water surrounded the tissue but was not in direct contact with it, some protection from freezing was afforded as compared with material lacking such treatment. As previously noted, the amount of protection seemed directly proportional to the volume of water used. In the case in which the roots were immediately surrounded by water, the protective influence was less pronounced. This may have been due

in part to an increased moisture content of the tissue brought about by several hours of exposure in the water.

Among the roots used in these tests, thirty-six were covered with paraffin and were tested at different temperatures. Of these roots, twenty-five suffered considerably more injury in the three outer tissues than did the corresponding checks, eight seemed to be injured somewhat less than the normal, and three showed injury similar to that in the untreated roots. The removal of the paraffin immediately after the exposure seemed inconsequential.

The cause for this behavior is not readily apparent, unless, perhaps, it may be associated with the phenomenon of supercooling. According to this hypothesis, the coating of paraffin might have functioned to delay ice formation in the tissue by preventing normal inoculation from the surface crystals, thus prolonging the supercooling period. The surrounding air temperature constantly being lowered, more serious damage might have resulted from rapid freezing once ice crystallization began.

INFLUENCE OF THE SCION ON THE HARDINESS OF ONE-YEAR ROOTS OF THE STOCK

In February, 1916, 640 piece-root apple grafts were made, the varieties Tompkins King, Baldwin, Oldenburg, and McIntosh being used as scion wood. These varieties were selected for the scions because of the well-known difference in the hardiness of their twigs. The stocks were taken from long-rooted American seedlings. Each stock was cut into four equal parts, from three to four inches in length. Since the lower pieces of a seedling are smaller than the crown cut, each variety was grafted on each of the four cuts, in order to exclude any variation from this source. This gave sixteen possibilities, each represented by forty plants. The column in table 11 headed " Section of stock " indicates the cut of the stock used; for example, section 1 is the crown cut, section 2 is the first cut below the crown, and so on.

This material was planted out rather early and was given average care thru the summer. The roots were dug after the leaves had fallen, and were placed in common storage until tested. Only the roots that had developed in 1916 from the parent stock were used. They were rather abundant at the lower callus, and were generally from two to three millimeters in diameter. Other roots of the American and French apples were tested from time to time for comparison.

TABLE 11. Influence of the Scion on the Hardiness of One-Year Roots of the Stock

Temperature (centigrade)	Date of freezing	Variety	Section of stock	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
							Cambium	Phloëm	Cortex
—10°	February 21 to 24	McIntosh	1	3 x 3	5	5	......	....	......
			4	3 x 2	5	5	15	....	......
		Oldenburg	3	3 x 2	5	4	......	....	......
			4	4 x 3	5	5	......	....	......
			4	3 x 2	8	8	......	....	......
		Baldwin	1	3 x 3	5	5	......	....	......
			4	3 x 3	5	5	......	....	......
		Tompkins King	4	3 x 3	8	7	50	50	50
			1	3 x 2	5	5	......	....	......
		American	......	3 x 3	4	4	......	....	......
				3 x 2	3	2	......	15	15
		French	....	3 x 2	4	4	......	....	......
—11°	February 17	McIntosh	2	4 x 3	5	5	......	....	......
			3	4 x 3	5	5	......	....	......
			3	3 x 2	4	4	......	....	......
		Oldenburg	2	4 x 3	5	5	......	....	......
			3	3 x 2	10	10	......	....	......
		Baldwin	2	4 x 3	6	4	15	15	15
			3	4 x 3	3	3	......	....	......
			3	3 x 2	12	11	15	15	15
	February 21	McIntosh	2	3 x 2	13	10	25	....	......
		Oldenburg	1	3 x 2	7	5	25	....	......
			2	3 x 2	8	4	30	....	......
		Baldwin	1	3 x 2	13	13	......	....	......
			2	3 x 2	8	5	25	....	......
		Tompkins King	1	3 x 2	8	6	50	25	25
			2	3 x 2	10	....	15	15	15
		American	....	4 x 3	6	6	......	....	......
		French	....	3 x 2	4	4	......	....	......

TABLE 11 (*continued*)

Temperature (centigrade)	Date of freezing	Variety	Section of stock	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
							Cambium	Phloëm	Cortex
—11° (*conc.*)	March 3	American	.....	3 x 2	6	4	20	20	20
		French	......	3 x 2	6	4	20	20	20
—11.5°	February 28	McIntosh	1 4	3 x 2 3 x 2	5 6	5 6	... ...	....	....
		Oldenburg	3	3 x 2	5	......	50	50	50
		Baldwin	3 1	3 x 2 3 x 2	5 3	1 3	50 ..	50	50 ....
		Tompkins King	2	3 x 3	5	2	40	40	40
		American	.....	3 x 2	5	1	50	50	50
		French	.....	3 x 2	5	....	70	70	70
—12°	February 17	McIntosh	1 4	3 x 2 3 x 2	5 6	....	100 100	100 100	100 90
		Oldenburg	3 4	3 x 2 3 x 2	6 7	....	60 70	60 70	60 70
		Baldwin	1 4	3 x 2 3 x 2	6 6	....	70 90	70 90	70 90
		Tompkins King	1 3	3 x 2 3 x 2	5 6	....	75 60	75 60	75 60
		American	.. .	4 x 3 3 x 2	2 5	....	75 80	75 80	75 80
		French	.. ....	4 x 3 3 x 2	2 5	....	90 100	90 100	90 100
	February 26	McIntosh	2 3	4 x 3 4 x 3	5 5	....	60 80	60 80	60 80
		Oldenburg	2	4 x 3	6	3	20	20	20
		Baldwin	2 3	4 x 3 4 x 3	5 5	... .	100 85	100 85	100 85

TABLE 11 (*concluded*)

Temperature (centigrade)	Date of freezing	Variety	Section of stock	Diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
							Cambium	Phloëm	Cortex
—12° (*conc.*)	February 26 (*concluded*)	Tompkins King	2 3	4 x 3 4 x 3	5 5	....	80 45	80 45	80 45
		American	....	4 x 3	5	....	70	70	70
		French	....	4 x 3	4	....	100	100	100
	March 1 to 3	McIntosh	1 2 3	3 x 2 3 x 2 3 x 2	5 10 5	....	100 60 100	100 60 100	100 60 100
		Oldenburg	1–4 2 3	3 x 2 3 x 2 3 x 2	12 5 7	2 1	55 80 70	55 80 70	55 80 70
		Baldwin	1 3 3–4	3 x 2 3 x 2 3 x 2	5 3 11	 1	70 85 70	70 85 70	70 85 70
		Tompkins King	1–3 2 3	3 x 2 3 x 2 3 x 2	11 6 6	....	90 90 70	90 90 70	90 90 70
		American	....	3 x 2	18	....	70	70	70
		French	....	3 x 2	14	....	70	70	70

The results shown in table 11 require but little comment. At a temperature of −10° C., as was expected, only a negligible amount of injury occurred in any roots. Likewise at −11° most of the root tissues escaped severe browning. An exposure to −12°, however, resulted in serious injury in practically all the roots tested. The temperature of −11.5° suggests a point below which most of the roots are killed, and above which little or no injury takes place in any variety.

The above observations are limited in extent and might not apply to other conditions. However, an analysis of these particular data seems to indicate strongly, not only that the size of the section of root used for the stock has no influence on the freezing point of the new roots, but also

that there are no constant nor considerable differences in hardiness of the roots developed from any of the four different varieties. It is shown further that there is no significant variation in the hardiness of the grafted and the seedling stock.

EFFECT OF SUGAR SOLUTIONS, WATER, AND DRYING OUT, ON THE RESISTANCE OF APPLE ROOTS TO FREEZING

Since a number of investigators have found that certain solutions have various influences on plant tissue with reference to freezing resistance, data were procured to ascertain whether or not similar effects could be observed in the roots. Before consideration of table 12, containing these data, it seems well to briefly mention some of the results reported regarding the influence of moisture content and the concentration of cell sap on the freezing to death of plant tissue.

It is well known that air-dried seeds can resist a very low temperature, but if allowed to absorb water they are frozen rather easily. Müller-Thurgau (1880) found that succulent tissue has a higher freezing point than material with a lower moisture content. Shutt (1903), Selby (1908), Shaw (1911), and Beach and Allen (1915) seemed to find that apple twigs are tender in proportion to the higher moisture content. Mix (1916), on the contrary, reported that tissue from the trunk of apple trees soaked in distilled water for an hour and then frozen was not injured more than normal untreated material.

Bartetzko (1910) found that Aspergillus, Penicillium, and other fungi grown in nutrient solutions of varying concentration, increased their resistance to freezing in proportion to the increase in the osmotic strength of the solution. Ohlweiler (1912) observed that in species of Magnolia in which the cell structure of the leaves was essentially the same, the concentration of sap was an indication of the relative hardiness of the species. Chandler (1913:181) stated, in summarizing his experience in connection with the relation of sap concentration to hardiness, "In case of plants not in a resting condition, a large amount of dissolved material either in the sap within the cell or in a solution surrounding the cell, will protect the cell from injury due to low temperature, to some extent at least." Chandler noted also that apple roots kept in water for eighteen hours were more severely injured than similar material dried in the air for the same period.

Maximow (1914) studied at length the influence of several organic and mineral solutions on the protection of red cabbage and tradescantia cells from cold. He found marked protection from these compounds, except when the solution was of a toxic nature or when it precipitated its solutes at a temperature near the freezing point of the cell sap. Not all of the increased cold resistance, however, was explained by the differences in the depression of the freezing point of the sap.

In these observations (table 12) the concentration of the cane sugar solutions to which the apple roots were exposed varied from 0.1 gram to 3 grams molecular. The length of exposure ranged from twenty minutes to ninety-six hours. Similar treatment was given using tap water instead of a sugar solution. In no cases were the roots frozen in the solutions, as in Maximow's (1914) experiments, and the free surface moisture was always removed. The roots were allowed to dry out at storage or laboratory temperature for from fourteen to sixty-eight hours. In a few instances both the drying-out and the solution treatment were given the same root.

TABLE 12. EFFECT OF VARIOUS PREVIOUS TREATMENTS ON THE FREEZING TO DEATH OF AMERICAN APPLE ROOTS

Temperature (centigrade)	Date of freezing	Previous treatment	Average diameter of roots (millimeters)	Number of roots	Number of roots uninjured	Per cent of cells killed in injured roots		
						Cambium	Phloem	Cortex
—8°	April 28	Untreated..........	7 x 6	4	....	25	10	10
		18 hours at 22° in laboratory..........	7 x 7	7	7	....	....	......
		18 hours in tap water....	8 x 7	3	....	50	40	......
		Same treatment......	6 x 6	2	....	70	....	......
		18 hours in 0.1 gram cane sugar solution.........	7 x 6	7	....	55	20	......
		18 hours in 0 05 gram salt solution	8 x 6	3	1	15	10	......
—9°	May 1 to 2	Untreated..........	7 x 6	16	5	60	20	15
		18 hours at 8° in storeroom..........	7 x 7	2	1	40	....	......
		44 hours as above....	7 x 6	4	3	10	10	......
		44 hours at 22° in laboratory..........	8 x 6	7	6	10	10	......
		68 hours as above......	6 x 5	6	5	65	65	65
		44 hours in tap water...	7 x 7	4	....	100	100	100
		68 hours as above ...	7 x 6	4	....	100	100	100
		68 hours in 0.1 gram cane sugar solution......	7 x 6	4	....	100	100	100
		44 hours in 0 2 gram cane sugar solution	8 x 7	4	....	100	100	100
		68 hours as above ..	7 x 7	6	....	80	70	60
		44 hours in 0.1 gram salt solution..........	8 x 7	4	1	70	35	5
		68 hours as above.......	8 x 7	4	....	100	90	80

TABLE 12 (*concluded*)

Temperature (centigrade)	Date of freezing	Previous treatment	Average diameter of roots (millimeters)	Number of roots	**Number of roots uninjured**	Per cent of cells killed in injured roots		
						Cambium	Phloem	Cortex
—10°	May 5 to 10	Untreated	7 x 6	23	5	65	30	20
		48 hours at 8° in storeroom.................	7 x 6	5	3	10	....	......
		48 hours at 22° in laboratory................	7 x 7	2	2	....	....	......
		24 hours in tap water. ..	7 x 7	2	....	100	100	100
		48 hours as above	7 x 6	8	....	90	90	85
		24 hours in 0.5 gram cane sugar solution.........	7 x 6	2	....	100	100	100
		48 hours as above	7 x 7	4	....	100	100	100
		72 hours in 0.5 gram cane sugar solution; 16 hours at 22° in laboratory. .	6 x 5	3	1	65	50	50
		20 minutes in 1 gram cane sugar solution.........	7 x 7	2	2	....	....	......
		24 hours as above.......	7 x 6	2	....	100	100	100
		48 hours as above.......	7 x 7	4	....	75	75	75
		72 hours as above......	7 x 7	4	....	80	80	80
		96 hours as above.....	6 x 5	5	....	100	100	100
		72 hours in 1 gram cane sugar solution; 16 hours at 22° in laboratory .	6 x 5	5	1	75	60	......
		20 minutes in 2 grams cane sugar solution ...	7 x 7	2	2	....	....	......
		24 hours as above	7 x 6	4	....	100	100	100
		48 hours as above......	7 x 7	4	....	75	75	75
		72 hours as above	6 x 5	2	....	100	100	100
		76 hours as above.. .. .	9 x 8	1	1	....	....	......
		72 hours in 2 grams cane sugar solution; 16 hours at 22° in laboratory	7 x 6	5	1	90	55	50
		20 minutes in 3 grams cane sugar solution	7 x 7	2	....	100	100	100
		48 hours as above	7 x 7	7	....	100	100	90
		72 hours as above..... .	6 x 5	2	....	100	100	100
		72 hours as above......	9 x 8	4	....	100	45	30
		72 hours in 3 grams cane sugar solution; 16 hours at 22° in laboratory	6 x 5	2	....	100	100	100
		96 hours at 22° in laboratory; no injury at -10°, then 48 hours in tap water............. ...	8 x 7	2	....	100	100	100

It is readily seen, in essentially all cases in table 12, that the roots kept in cane sugar and salt solutions longer than twenty minutes were injured more than the untreated tissue and about the same as the roots placed in water. On the other hand, roots dried in the air at 8° and 22° C. exhibited less killing than the normal tissue. These conclusions seem true regardless of the freezing temperature used, the time exposure above eighteen hours, or the concentration of the solution employed. The few roots exposed for twenty minutes in sugar solution did not decrease in resistance. More

examples are necessary, however, before these data can be considered dependable.

An interesting fact brought out in this connection is the effect of drying after exposure to a sugar solution. While the roots scarcely recovered normal hardiness in most instances, the percentage of injury was somewhat lessened except when small roots were employed. In the last case shown in table 12, two roots exposed to –10° C. without injury were killed thruout after remaining in tap water for forty-eight hours.

Unfortunately, at the time of this study not enough material was available to determine the freezing-point depression of the sap of the roots kept in sugar solutions. If the sap concentration was increased by such treatment, another factor, or other factors, inhibited its action in lowering the freezing point of the tissue.

According to table 9 (page 643) the depression of the American-grown apple root would indicate a concentration of about 1.33 gram molecular. Since the concentration of the sugar solutions ran as high as 3 grams molecular, either plasmolysis or an increase in the concentration of cell sap would be expected. To determine this point, sections of roots exposed to the various concentrations used in the experiment just described were examined under the microsope. In all cases the cells appeared normally turgid.

The cause of the severer injury to cells of higher moisture content, while often observed, is also rather obscure. It seems, however, that if both the moist and the dry tissues possessed the same initial concentration, at an air temperature of –9° or –10° C. both should possess the same amount of water in the cells, regardless of the injury. Indeed, both have given up the identical amount of water at –10° C., the dry root having lost its water thru evaporation and ice formation, the moist root thru ice formation only. This reasoning suggests that the greater injury in the moist cells may be due to a larger ice mass formed in them. It suggests further that causes other than dehydration must account for the phenomenon of freezing to death of plant tissue.

SUMMARY

There is little difference in hardiness of the roots between American and French apple seedlings. Normal one-year roots are hardier than one-year stocks held one year in cold storage or grown in the field a second year.

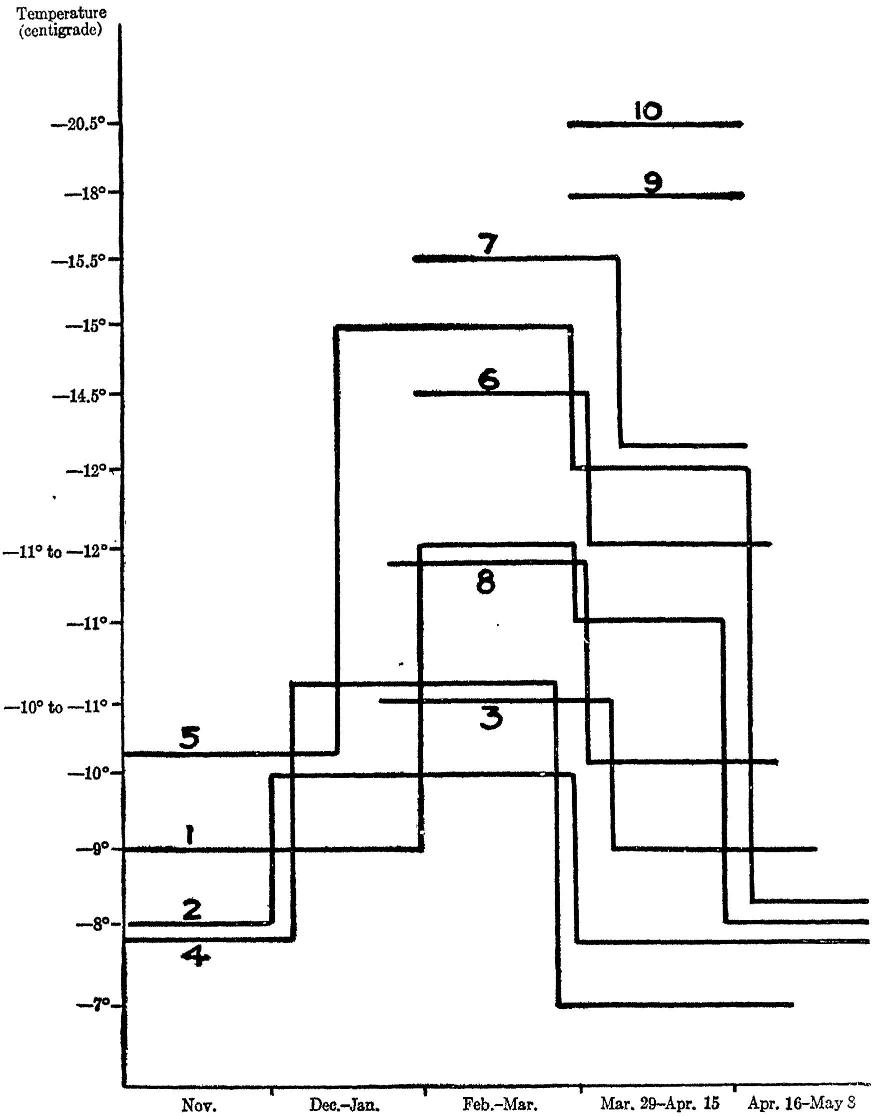

FIG. 164. SEASONAL HARDINESS OF FRUIT ROOTS

1, Apple (French "crab"), and grape (Lindley, Norton, and Cynthiana). 2, Pear (French) and plum (Myrobalan). 3, Peach. 4, Cherry (Mazzard). 5, Cherry (Mahaleb). 6, Grape (Diamond). 7, Grape Clinton and Concord). 8, Raspberry, blackberry, and dewberry. 9, Currant. 10 Gooseberry

The state of maturity and the diameter of the roots were the important factors in determining the resistance to freezing of all species tested in these experiments.

The French pear stock seems more tender than the Kieffer stock. Both roots are less resistant to freezing than is the apple.

Peach roots on which the variety Elberta had been budded proved less hardy than the apple and about equal to the Kieffer pear.

The order of hardiness of the four cherry stocks tested is as follows: Mahaleb, *Prunus Besseyi*, *Prunus pennsylvanicum*, Mazzard. The Mahaleb stock is considerably superior to the apple, while the Mazzard is about equal to the French pear.

Myrobalan plum roots are quite as easily killed by low temperature as are the French pear and the Mazzard cherry.

In the six varieties of grapes studied, the roots of the Clinton and the Concord are as hardy as the root of the Mahaleb cherry. The Diamond is slightly less hardy. The roots of the varieties Lindley, Norton, and Cynthiana are more resistant than the root of the Mazzard cherry but less resistant than the apple root.

No significant differences are seen between the hardiness of the blackberry root and that of the red raspberry root. The Lucretia dewberry, however, is slightly less tender than either, and is about equal to the apple stock.

Roots of the Downing gooseberry are more resistant to freezing than are Wilder currant roots. The roots of the gooseberry and the currant seem much hardier than any other roots examined.

The freezing-point depression of the Wilder currant sap is greater than that of the apple sap. Sap from the upper half of American-grown apple roots is of a higher concentration than that from the lower half of the same roots. The upper half of the root is also somewhat more resistant to cold.

A rapid fall in temperature is shown to increase the freezing injury in apple roots.

The placing of soils of different moisture content in the freezing chamber around the roots causes no appreciable difference in the amount of injury.

A majority of roots entirely covered with melted paraffin killed more severely than did similar untreated roots.

Water, when placed in the same test tube with the root tissue or when placed around it in another container, often provides protection against a low temperature, until all the water is frozen.

The hardiness of the scion does not seem to affect the resistance of the one-year roots of the apple stock.

Roots placed in sugar solutions varying in concentration from 0.1 gram to 3 grams molecular, are injured more easily than are normal roots. Roots allowed to absorb moisture for several hours are similarly injured.

In nearly all cases in which the material was allowed to dry, its resistance was increased.

The difference in the response to cold of the moist tissue and the dry tissue may be due to the smaller ice mass formed in the dry root.

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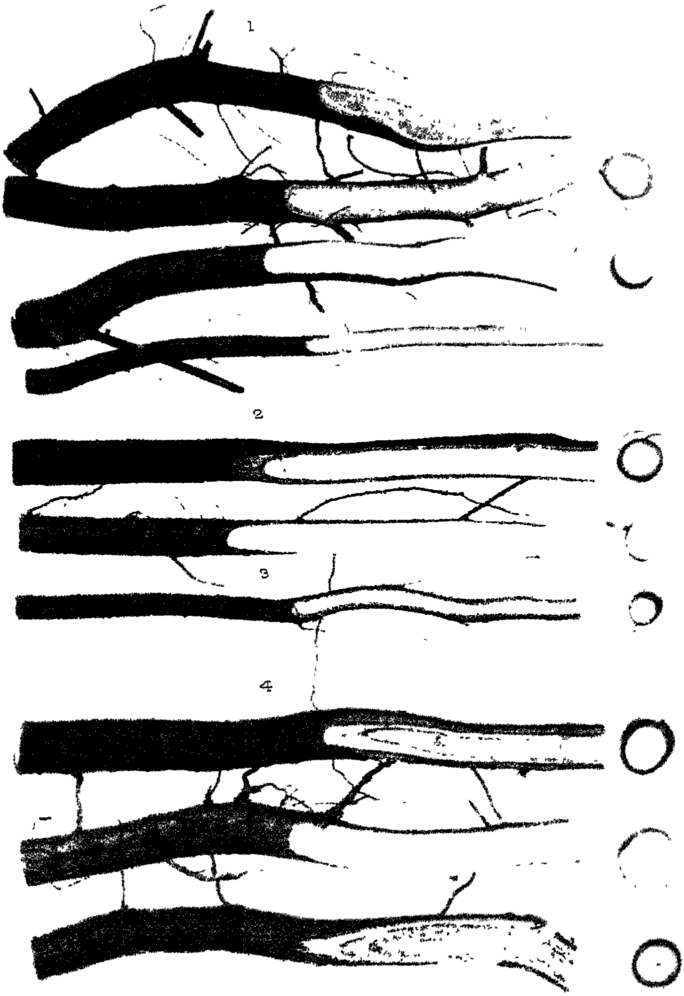
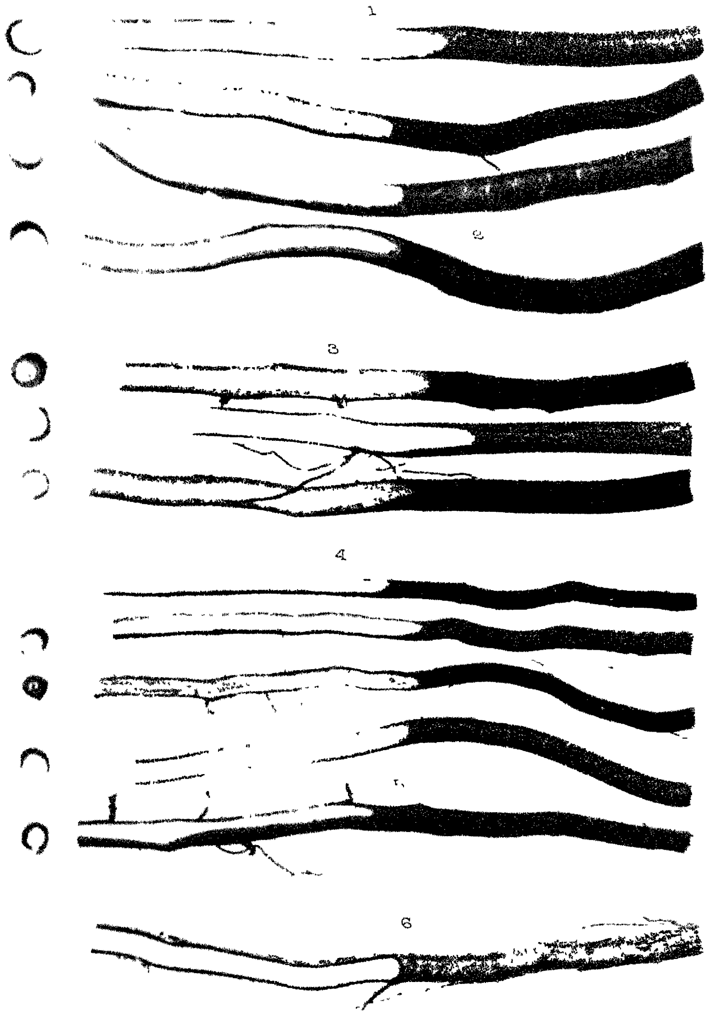


FREEZING INJURY IN ROOTS OF SOME FRUIT SPECIES
1, Apple. 2, European pear; 3, Kieffer pear. 4, Elberta peach



FREEZING INJURY IN ROOTS OF SOME FRUIT SPECIES

1, Morello cherry; 2, Mahaleb cherry. 3, Myrobalan plum. 4, Concord grape. 5, Red raspberry. 6, Gooseberry, uninjured after fifteen hours exposure at –22° C.